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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Edited by ROBERT P. BIGELOW, PH D.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.**

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AND

PROCEEDINGS OF THE SOCIETY OF ARTS

VOL. XVIII MARCH, 1905 No. 1

PROCEEDINGS OF THE SOCIETY OF ARTS

FORTY-THIRD YEAR, 1904-1905

BOSTON, October 13, 1904.

THE 598th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, October 13, at eight o'clock, President Pritchett in the chair. Forty-two persons were present.

After the minutes of the previous meeting had been read and approved, Mr. Alfred D. Nutter and Mr. Robert S. Allyn were elected to Associate Membership in the Society.

Professor Thomas A. Jaggar, Jr., then addressed the Society on "Geology as an Experimental Science," and showed by means of slides how the processes of erosion, faulting, and upheaval may be studied experimentally. A vote of thanks was tendered to the speaker, and the meeting adjourned.

BOSTON, October 27, 1904.

The 599th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, October 27, at eight o'clock. Professor Cross was in the chair. One hundred and six persons were present.

The minutes of the previous meeting were read and approved. The chairman then presented Mr. Albert H. Munsell, of Boston, who addressed the Society on "A Practical Color System based upon Photometric Measurements."[1] The lecture was illustrated by apparatus, models, diagrams, and experiments. An interesting discussion followed the lecture. A vote of thanks was tendered to the speaker, and the meeting was adjourned.

BOSTON, November 10, 1904.

The 600th regular meeting of the SOCIETY OF ARTS was held at Huntington Hall, Rogers Building, on Thursday evening, November 10, at eight o'clock. About two hundred persons were present. Professor Porter, of the Department of Sanitary Engineering, presided. The minutes of the previous meeting were read and approved.

The Society then listened to a very interesting and instructive address by Mr. J. Pickering Putnam, architect, of Boston, who spoke on "Sanitary Plumbing and Our Plumbing Laws, with Suggestions for Their Revision and Simplification."[2] The lecture was illustrated with lantern slides and with special apparatus constructed for this occasion, which showed the phenomena connected with trap siphonage and demonstrated that simpler methods of plumbing may be substituted for the present complicated ones with no diminution of the safety attained. After the address a discussion of the subject was participated in by Professor T. M. Clarke, Mr. J. Randolph Coolidge, Jr., Dr. T. M. Rotch, Mr. David Craig, President of the Master Plumbers' Association of America, Mr. Arthur G. Everett, Mr. W. H. Sayward, from the Master Builders' Association, and Dr. J. J. Putnam. A vote of thanks was extended to the speaker, and the Society adjourned.

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[1] See below, pp. 60–72.

[2] TECHNOLOGY QUARTERLY, 17, No. 4, December, 1904, pp. 308–332.

BOSTON, November 23, 1904.

The 601st regular meeting of the SOCIETY OF ARTS was held in the lecture room of the Boston Society of Natural History, corner of Boylston and Berkeley Streets, on Wednesday evening, November 23d, 1904, at eight o'clock. About two hundred persons were present. The records of the previous meeting were read and approved.

The Society then listened to an extremely interesting address by Mr. Desmond FitzGerald, C.E., the Special Sanitary Commissioner to the Philippine Islands, "On Manila and the Philippines as They Are Today." The speaker described the sanitary condition of Manila, and spoke of the work of the government in various departments. The lecture was illustrated with a large number of interesting lantern slides. A vote of thanks was extended to the speaker, and the Society adjourned.

BOSTON, December 8, 1904.

The 602d regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, December 8, 1904, at eight o'clock, Professor Jaggar in the chair. About two hundred persons were present. The records of the previous meeting were read and approved.

The Society then listened to an extremely interesting address by Mr. Edmund Otis Hovey, of the American Museum of Natural History, New York, on "Mont Pelée and the Eruptions of 1902; the Growth of the Wonderful Spine." The lecture was illustrated with a large number of interesting lantern slides. A vote of thanks was extended to the speaker, and the Society adjourned.

BOSTON, January 12, 1905.

The 603d regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, January 12, 1905, at eight o'clock. Dr. R. P. Bigelow presided. About forty-five persons were present. The records of the previous meeting were read and approved.

The Society then listened to an address by Dr. H. J. Webber, of the Division of Plant Breeding, Department of Agriculture at Washington, on "The Evolution and Improvement of Domestic Plants." Dr. Webber discussed the methods by which new varieties of plants are produced, and described in detail the experiments carried on by the Department of Agriculture with a view to obtaining new kinds of plants of economic importance, such as cotton, cereals, fruits, and the like. The lecture was fully illustrated by lantern slides, many of which showed successive stages in development which have been produced by cultivation. A vote of thanks was extended to the speaker for his very interesting address, and the Society adjourned.

SAMUEL C. PRESCOTT, *Secretary.*

CONTRIBUTION TO THE BIOCHEMISTRY OF SEWAGE PURIFICATION

THE BACTERIOLYSIS OF PEPTONES AND NITRATES[1]

BY STEPHEN DEM. GAGE

(Received January 28, 1905)

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[1] Read at the Thirty-first General Meeting of the American Chemical Society, Philadelphia, December 29, 1904, and to be published also in Jour. Amer. Chem. Soc.

[2] The studies herein reported were made at the Lawrence Experiment Station, under the general direction and with the coöperation of Mr. H. W. Clark. In the chemical analyses the writer has been assisted by Mr. George O. Adams, who has also aided in the elaboration of the methods and in the discussion of the significance of the results. In reviewing the literature free use has been made of the various publications of Rideal, Chester, and Lipman, and in many instances, where the original literature was not obtainable, citations have been made from the reviews of these authors.

Introduction

In the biological treatment of sewage, a large number of complex chemical reactions occur, and many types of bacteria are active, some of them playing a good part in the purification, while others exert a hindering action. Hitherto the analyst has relied on chemical methods in order to judge of the degree of purification accomplished by a given sewage system, and indeed, so far as they go, the chemical methods have been sufficient for that purpose. In the use of the so-called biological sewage-disposal systems, however, with their more scientific control, it has been found that the chemical methods of the present time are inadequate, inasmuch as they do not show what processes are active within the filtration plant further than can be shown by the end products — that is, they do not show in what manner those end products are produced, nor do they indicate in what manner the intermediate processes may be controlled in order to accomplish the greatest amount of purification in the most economical manner. While much knowledge of the methods of filter control has been obtained, this knowledge has been acquired by the cut and try method rather than by the study of the processes going on in the filters and of the different types of bacteria which are responsible for the various types of reaction.

It has often been noticed that while one method will dispose of a certain sewage in a satisfactory manner, a very different result is obtained when we attempt to treat a different sewage by this process, and this has led to the axiom that the problem of finding a satisfactory method of disposal is an individual one for each sewage. The reason for this is twofold: first, the very great variation in the character and amount of the components of the sewage; and second, the difference in the active bacterial flora of that sewage.

During the past few years much study has been given to the bacteriology of sewage at the Lawrence Experiment Station, and recently new methods have been devised for the study of the functions of the bacteria concerned in the purification of sewage, and these methods, with some of the results obtained by their use, have already been published.[1] In the treatment of sewage, the main problem is to accomplish the change of the nitrogenous matter from the organic to the inorganic form, since in the process of changing the form of the nitrogen the carbonaceous matter, except perhaps a very small

[1] For this reference and those following see Bibliography, p. 37.

portion, is usually taken care of. Thus a knowledge of the bacterial flora of sewage and of the changes which different types of bacteria may cause in the form of the nitrogen of that sewage becomes of considerable importance in the proper control of those changes. The greatest difficulty in investigations of this character is the uncertainty as to the organisms in the sewage. The least change in the conditions of the experiment and new species of bacteria develop, with perhaps a total change in the character of the chemical reactions produced — assuming that the experiment is conducted under conditions similar to those under which sewage disposal systems are operated. In order to understand the fundamental principles of sewage purification, it becomes necessary to study the functions of the various species of bacteria in pure culture and under conditions which can be controlled, for it is only by such methods that data may be obtained sufficiently exact to be used in an analysis of the more complex problems where mixed cultures of bacteria are active and the products of their activity react upon one another. The present paper has to deal with the changes caused in the nitrogen content of known solutions by pure cultures of bacteria.

Methods of Investigation

The method employed in this experiment has been to inoculate with pure cultures of bacteria two solutions, one (*A*) containing nitrogen in the form of peptone, and the other (*B*) containing peptone and nitrogen in the form of potassium nitrate, and to determine accurately from day to day the changes taking place in the nitrogen contents of the solutions so far as could be judged by making quantitative tests of the amount of nitrogen present in the solutions as ammonia, as nitrates, and as nitrites, and by determining at the end of a stated period the total amount of organic nitrogen in the solutions by the Kjeldahl method.

The peptone solutions (*A*) have been uniformly composed of 0.1 per cent. of Witte's peptone in distilled water, with an organic nitrogen value of about fourteen parts of nitrogen per 100,000 as determined by the Kjeldahl method. It is well known that commercial peptones are not pure, and that they contain considerable amounts of albumoses and of other hydrolized albumens. This fact, however, is an advantage rather than a detriment in a study such as the present, since the cultural solutions simulate more closely the character of sewage, and are

at the same time of sufficiently definite composition to allow of their being readily duplicated in the laboratory.

The nitrated solutions (*B*) have been made up the same as the peptone solutions, with 0.1 per cent. of Witte's peptone in distilled water, and have been of three different strengths at different periods of the investigation, containing nitrogen as potassium nitrate equivalent to 2.7, 6.0, and 22.5 parts per 100,000.

The cultures selected were first purified by plating out on gelatin, and were then subjected to a thorough course of revivification by successive cultivations in broth, after which they were transferred to agar streaks. Glass-stoppered bottles, containing about 100 c.c. of the peptone solution and of the nitrated peptone solution, were then inoculated with a large loopful of the culture from the surface of the agar streaks, and, after thoroughly shaking, the bottle cultures were incubated at 20° C. Portions for analysis were removed from each bottle daily with sterile pipettes, each culture being thoroughly shaken before the sample was removed. At the end of the experiment, determinations were made of the total organic nitrogen in both cultures and uninoculated solutions.

By the use of peptone solutions of known strength both with and without nitrates, we have been able to determine approximately: (1) the amount of ammonia formed from the organic matter, that is, from the peptone; (2) the amount of ammonia formed from organic matter plus that formed by reduction of nitrates to nitrites; and (3) by subtracting the amount of ammonia formed from the peptone from that formed in the nitrated peptone solution, we obtain a value for the ammonia formed from the nitrates, although there is a large error in the use of this value, as will be shown further on; (4) we also obtain a value for the amount of nitrates destroyed by the culture by subtracting the amount of nitrate in the solution from that at the start; and (5) we get the amount of nitrites by direct reading. (6) By subtracting the sum of the nitrites and the estimated amount of ammonia formed from the nitrates from the total amount of nitrate reduced, we obtain a value for nitrogen from nitrates unaccounted for, which may have been liberated as free nitrogen. In obtaining this last value we have the sum of all the errors of the other determinations, so that the value is itself subject to much doubt; but some of the results have been so characteristic that they are used further on with no other apology. (7) By the use of the Kjeldahl values, in connection with the nitrate,

nitrite, and ammonia values, we are able to compute with more or less accuracy the gain or loss in the total nitrogen content of the test solutions. In addition to the study of the cultures mentioned, examinations have been made of a large number of cultures at the end of a seven-day incubation, and certain of these results are included here.

All of the methods, both chemical and bacteriological, have been subject to more or less unavoidable error. It should be borne in mind, however, that biological processes are always subject to a large variation, and that all results of biochemical investigation should be interpreted in that light. It has accordingly been considered sufficiently accurate to determine the various chemical factors to the nearest 0.1 part in 100,000, and to use the results so obtained for the purposes of discussion as though the errors had been eliminated.

Methods of Chemical Analyses

The methods for the quantitative determination of ammonia, nitrates, and nitrites in these solutions have varied somewhat from the usual procedure for water analysis. For the ammonia determination 1 c.c. of the solution was placed in the Nessler tube, made up to 50 c.c. with ammonia-free water, and nesslerized, direct readings being made against permanent standards.

The direct reading of the ammonia is preferable to the distillation method, as the partially decomposed bacterial products do not show as free ammonia in the direct reading, but many of them are broken down by heat and appear as free ammonia by the distillation process, giving values which are too high. The main objection to the direct reading is the green color which appears in many cultures upon nesslerizing, probably caused by the presence of amides. The green color interferes very much with the matching of the colors against the usual ammonia standards, and it was necessary to use a special set of standards in order to get comparable readings. These standards are a modification of Jackson's platinum cobalt standards,[2] in which the yellow is toned down by the addition of cupric chloride solution. There is considerable variation in the shade of different cultures of bacteria after nesslerization, and many experimental sets of standards were made up before the proportion of copper solution was finally decided upon. Since some of the cultures did not produce the objectional green shade, it was found advisable to keep on hand two sets of standards, one with and one

without the copper. The final composition of the special standards employed is shown in the following table.

TABLE I. — PERMANENT STANDARDS — NITROGEN AS AMMONIA — USED IN DETERMINING AMMONIFYING POWER

c.c. Standard.	c.c. Platinum solution.	c.c. Cobalt solution.	c.c. Copper solution.
0.1	1.8	0	0.6
0.3	3.2	0	1.3
0.5	4.5	0.1	1.8
0.7	5.9	0.2	1.8
1.0	7.7	0.5	1.5
1.3	9.4	0.9	1.5
1.7	11.5	1.7	2.0
2.0	12.7	2.2	2.0
2.5	15.0	3.3	0.5
3.0	17.3	4.5	0.0
3.5	19.0	5.7	0.0
4.0	19.7	7.1	0.0
4.5	19.9	8.7	0.0
5.0	20.0	10.4	0.0

Platinum solution = 2 grams potassium platinic chloride dissolved in a small amount of water. 100 c.c. of strong hydrochloric acid (sp. gr., 1.20) added and made up to 1 liter.

Cobalt solution = 12 grams cobaltous chloride dissolved in a small amount of water. 100 c.c. of strong hydrochloric acid added and made up to 1 liter.

Copper solution = 12 grams dry cupric chloride dissolved in water. 100 c.c. strong hydrochloric acid added and made up to 1 liter.

To determine the nitrites, 1 c.c. of the solution was mixed with 49 c.c. of nitrite-free water in the Nessler tube, and read by the usual Griess method. The nitrates were determined by placing 1 c.c. of the culture in round-bottom tubes, having a length of about 70 mm. and a diameter of 15 mm. These tubes were placed in wire racks and the contents evaporated to dryness on the water bath, or, better, in the hot air bath at a temperature of 115° to 125° C. Phenolsulphonic acid was then added directly to the tube, and by rolling the tube in the fingers was thoroughly incorporated with the residue. The contents of the tubes were then washed into Nessler tubes, ammonia was added, the contents made up to 50 c.c., and the amount of nitrogen as nitrates read against standards as usual. The evaporation in tubes is preferable to the usual evaporation in dishes, both for economy of space and ease in manipulation. Experiments showed that the evaporation to

complete dryness at these temperatures did not affect the accuracy of the determinations.

Source of the Cultures

The cultures selected were obtained from sewage and from the effluents of sewage filters during a study of the functions of the various kinds of bacteria concerned in sewage purification, and were selected as producing as many as possible of the various changes in the nitrogen contents of the test solutions. In all, some forty cultures were studied in detail, and from the results obtained twenty cultures have been selected as giving results sufficiently characteristic to warrant their being included here. The majority of the cultures not included gave results which showed nothing further than could be shown by the cultures presented, while others of the cultures omitted had breaks in the chain of results due to losses during chemical analysis. The cultures were isolated during February and March, 1904, as follows:—

Cultures 1, 16, 17, 23, 40, 41, from Lawrence Sewage.

Culture 18, from Septic Sewage.

Cultures 4, 7, 9, 10, 11, 13, 29, from the effluents of intermittent sand filters receiving Lawrence Sewage.

Culture 22, from the effluent of a contact filter receiving Lawrence Sewage.

Cultures 31 and 32, from the effluent of a contact filter receiving Septic Sewage.

Cultures 24, 26, 38, from the effluents of intermittent continuous filters receiving Lawrence Sewage.

It is not essential in a study of this kind that the names of the species be known. Indeed, in sewage disposal a determination of the presence or absence of definite species of bacteria, other than certain disease-producing organisms, is of small moment compared with the establishment and determination of the types which play important parts in the conversion of that sewage into a harmless and inoffensive water. While some progress has been made in the study of these cultures, the determinations of the species are not complete at the present writing. Enough work has been done, however, in order to be able to say that the cultures are apparently all different species, and indeed the variation in the nitrogen changes caused by these cultures would alone be almost sufficient to establish this difference.

Review of the Literature

We will now discuss the changes which may occur in nitrogenous matter and the agency of bacteria in causing those changes. As sources of nitrogen in the experimental solutions, we have peptone and atmospheric nitrogen common to both solutions. In the peptone solution the only changes which may be produced by bacterial action are the breaking down of the peptone into amides and amino acids, which themselves may then be broken down with the formation of ammonia or free nitrogen, the oxidation of the ammonia to nitrites and nitrates, and the fixation of atmospheric nitrogen. The process going on here is primarily either putrefaction or decay, the term putrefaction being used in the sense of breaking down without air, or anaërobic action; the term decay being used as indicating an oxidizing, or aërobic, action.

Owing to the newness of bacteriological methods of sewage disposal, we have to turn mainly to the agricultural chemists and bacteriologists for our knowledge of the biochemical processes by which nitrogen is changed from one form to another. As early as 1837, Schultze[3] and Schwann[4] discovered that the cause of putrefaction and decay was always present in unsterilized air, but it was left to Pasteur[5] and his colaborers to demonstrate that putrefaction was due to the action of microörganisms. The first step which takes place in the conversion of the albuminous matter in sewage is peptonization, or liquefaction of the insoluble proteids into soluble peptones and albumoses. The consideration of this step may be omitted here since we are starting with these latter products. The next step in the process is the conversion of peptones into amino acids and amides.

The amino acids are next decomposed into organic acids and free nitrogen or ammonia, the organic acids and the ammonia thus formed combining to form ammonium salts; but these salts are readily broken up and converted into carbon dioxide, water, ammonia, hydrogen, nitrogen, and marsh gas, the last three of which escape with some of the ammonia and carbon dioxide, leaving the rest of the ammonia and carbon dioxide united with the mineral elements in the solution or combined as ammonium carbonate.

Ammonification. — There is much experimental evidence to show that the production of ammonia from organic matter is characteristic of most species of bacteria. Marchal[6] found that out of thirty-one organisms studied, seventeen produced ammonia decidedly, and all of

the others gave a slight reaction. He observed that the conversion of organic matter into ammonia is inversely proportional to the amount of organic matter in solution, and varies with the character of the proteid matter, the breaking down of peptones being more rapid than that of most other albuminous compounds. Sewerin[7] found that the majority of bacteria which he studied produced ammonia, but the rate of ammonification was very variable, some of the species producing ammonia continuously from the start, while others did not show any reaction until after some days. Chester[8] found that the majority of common soil bacteria were able to produce ammonia, and also that the rate of ammonification in a soil which had been manured was directly proportional to the product of the numbers of bacteria in that soil by their relative ability to produce ammonia.

The increase of ammonia in sewage on standing and the conversion of organic nitrogen to ammonia in septic tanks and in contact filters are common knowledge in sewage analysis.

The ammoniacal fermentation of urea, while not directly applicable to the present experiments, has considerable significance in sewage treatment. This subject has been thoroughly studied by Pasteur,[9] Gabler,[10] Felz and Riter,[11] von Jaksch,[12] Miquel,[13] Leube,[14] Ladureau,[15] Warrington,[16] and a number of others. These investigators find that urea and uric acid are readily and completely fermented by a number of common bacteria, forming ammonia and carbonic acid, which combine and remain in solution unless further acted upon by other bacteria.

Nitrification. — The oxidation of ammonia to nitrites and nitrates has usually been considered to be the function of a specific class of organisms which will not grow on ordinary culture media, and hence cannot be included in the scope of the present study. The classical work of Winogradsky[17] and Warrington[18] with this class of organisms is too well known to require review here. At the same time there is some experimental evidence more or less authentic which would point to the fact that certain common species, not belonging to Winogradsky's group of nitrifying bacteria, are, under certain conditions, able to accomplish the oxidation of ammonia to nitrites and nitrates.

In 1886 Celli and Zucco[19] and Heræus[20] succeeded in isolating from water by the usual methods a number of species of bacteria which appeared to have feeble nitrifying powers. In 1895 Burri and Stutzer[21] isolated from soil an organism with nitrifying properties, and two years later Stutzer and Hertleb[22] offered a further confirmation of the earlier

work of Burri and Stutzer, in which they claimed not only to have made the nitrifying organism grow on all ordinary culture media, but also stated their belief that this organism had a pleomorphic habit, changing its form and character under different conditions. Much doubt has been cast on the purity of the cultures with which these investigators worked, and Fraenkel[23] claims to have isolated from Burri and Stutzer's cultures eleven different species.

In 1896 Woodhead[24] isolated from sewage a number of different species which grew well on ordinary culture media, some of them being denitrifying forms and others being able to oxidize nitrites to nitrates.

Richter[25] isolated a Micrococcus which reduced nitrates to nitrites and was also able to oxidize urea to nitrites. Furthermore, we must consider that the *symbiosis* of bacteria as regards action on nitrogenous bodies has been little studied. Indeed, it is an open question in the minds of many sewage and soil bacteriologists as to whether the so-called nitrifying group of bacteria are the sole cause of nitrification. That there is some ground for this doubt is instanced by many experiments in sewage treatment, in which sterile materials inoculated with pure cultures of these types fail to nitrify, or, at best, nitrify only very slowly when dosed with ammonia solutions or with sterile sewage, while control filters of the same material nitrify unsterilized sewage rapidly and completely.

As to the conditions governing nitrification there is some diversity of opinion. The earlier observers uniformly considered that nitrification was essentially an aërobic, or oxidizing, process. Holdefleiss,[26] on the other hand, obtained results in his experiments which would warrant the belief that nitrification may often take place under strictly anaërobic conditions. Further evidence of this has not been forthcoming, however, and the results obtained from the operation of sewage filters would indicate that efficient aëration is necessary if nitrification is to continue. Leme,[27] Pickard,[28] and others have shown that an excess of organic matter tends to check or prevent nitrification. Davy[29] observes that the reduction in nitrification is especially marked when the excess of organic nitrogen is of animal origin. The sudden stoppage of nitrification in sewage filters when continually overdosed, and the return of this action when the quantity of organic matter applied has been reduced within the proper limits, are common knowledge to all who have had experience in the operation of sewage disposal works. The conditions affecting nitrification by sewage filters and the amount

of nitrogen which these filters will nitrify regularly have been exhaustively studied at the Experiment Station, and will be found discussed in the annual reports of the Massachusetts State Board of Health since 1890, under the chapters on filtration of sewage.

Liberation of Nitrogen. — There is considerable difference of opinion as to whether or not free nitrogen is formed in the breaking down of peptones and amino acids. The results of Immendorff,[30] Kellner,[31] Tacke,[32] Ehrenberg,[33] Schlössing,[34] Muntze, Girard and Schneidewind,[35] Dietzell,[36] and Pfeiffer[37] would appear to support the view that no free nitrogen is evolved when the reactions take place under strictly anaërobic conditions. On the other hand, Wollney[38] takes the stand that nitrogen may be given off in putrefaction, and quotes the results of König and Kiesow,[39] Dietzell,[40] and Morgen and König[41] to support his arguments. Zoja[42] found that elastin when fermented under anaërobic conditions gave off free nitrogen. Wood and Wilcox[43] found that *Bacterium furfuris*, which they believed to be the cause of putrefaction in the tanning industry, liberated nitrogen gas from nitrogenous matter in the presence of starch under anaërobic conditions. Hugonenq and Doyon[44] found that under anaërobic conditions *Bacillus typhosus* and *B. tetanus* evolved considerable amounts of free nitrogen from nitrogenous solutions. The composition of gases given off from putrefying sewage in septic tanks has been carefully studied during the past few years by a number of observers. Although the percentage composition of the gases given off by septic tanks in different places has varied widely, in every case a considerable percentage of nitrogen has been reported, some of the results being as follows: At Lawrence, Massachusetts,[45] the gases from two different tanks contained 16 per cent. and 19 per cent. of free nitrogen, respectively. At Andover, Massachusetts,[45] the gas contained 61 per cent. nitrogen. At Worcester, Massachusetts, Kinnicut[46] found the gas to contain about 17 per cent. of nitrogen. Rideal[47] found that two samples of gases given off from the tank at Exeter, England, contained 39 and 61 per cent. of free nitrogen, respectively. Fowler[48] reports the gas from the tank at Manchester, England, to contain 16 per cent. of free nitrogen.

There is also a difference of opinion as to whether nitrogen is liberated in decay, that is, when the decomposition takes place in the presence of air. Ehrenberg,[49] by a long series of experiments in which he made careful measurements of the gases evolved, decided that no gaseous nitrogen was evolved. Hufner[50] also coincides in the opinion

that no nitrogen is liberated in decay proper. Kellner and Yoskii[51] found that the loss of nitrogen during decay was very small, even when the experiment was carried over a long period. On the other hand, the results obtained by Tacke[52] led him to believe "that in the oxidation of ammonia, as well as in the reduction of nitric acid to ammonia, conditions may arise by which two nascent nitrogen atoms can combine into molecular nitrogen and escape from the decaying mass." Chabrier[53] found that small amounts of nitrogen are always liberated during nitrification, and his observations have been confirmed by Boussingault,[54] by Pickard,[55] and more recently by Godlewski.[56] Schneidewind,[57] Pfeiffer,[58] and Stutzer and Hertleb[59] all furnish evidence that losses of free nitrogen are likely to occur.

Gerlach and Vogel[60] isolated from soil a number of bacteria which were able to transform soluble inorganic salts into insoluble organic nitrogen, but when organic nitrogen was present this transformation into proteids was always accompanied by a loss of free nitrogen.

Rogoyski[61] arrived at similar conclusions concerning the simultaneous liberation of nitrogen and the fixation of soluble nitrogen as proteids, and also determined that the proteid nitrogen so formed appeared to be non-putrescible and readily nitrifiable without intermediate conversion into ammonia. This latter point is worthy of further study, bearing as it does on the storage of nitrogen in sewage filters at times and the ultimate disappearance of this stored nitrogen with the appearance of large amounts of nitrates and nitrites in the filter effluents.[62] Proteids of this class may also form a large percentage of the organic matter in the sediment in the effluents from filters of coarse materials operating at high rates, which, although usually very turbid and containing considerable suspended organic matter, have been repeatedly proved to be non-putrescible.[63] Berthelot,[64] studying the volatility of the ammonia from soil, found that when there was a loss of ammonia extensive loss of free nitrogen occurred at the same time. The same author observes that the activity of bacteria in soils may lead to a very considerable loss of nitrogen either as ammonia or as elementary nitrogen, and the evolution of free nitrogen is independent of the presence or absence of nitrates. Lipman[65] describes an interesting experiment in which he proved that *Bacillus pyocyaneus* caused a greater loss of nitrogen in solution as the surface of the solution exposed to the air was increased. The better aëration thus produced was evidently the cause of the greater

loss, although he did not determine definitely whether the loss was due to increased volatilization of the ammonia, or, as was more likely, to the increased oxidation and setting free of elementary nitrogen. Rideal[66] has calculated the amount of oxygen necessary to completely oxidize certain typical organic compounds either to ammonia or to elementary nitrogen, and it is significant that more oxygen is required for the second reaction than for the first. This would go to prove that nitrogen is more likely to be set free under aërobic than under anaërobic conditions.

Fixation of Atmospheric Nitrogen. — As to the fixation of atmospheric nitrogen in organic solutions, there is also considerable controversy, and the available data is very meagre. Laurent[67] found that certain algæ in *symbiosis* with bacteria were able to fix nitrogen in sand which was exposed to the air and sunlight. This observation was confirmed by Bouilhac,[68] who decided that the bacteria were the cause of the fixation of the nitrogen, the algæ merely furnishing the food supply for the bacteria, and this view has more recently been substantiated by the experiment of Kruger and Schneidewind.[69] Nobbe and Hitner[70] observed that there was a fixation of nitrogen in soils, and attributed this action to the agency of microörganisms. Stoklasa and Vitek[71] believed that many of the denitrifying bacteria under certain conditions have the power to fix atmospheric nitrogen, basing their belief on the fact that in their experiments *Bacillus ellenbachiensis* fixed atmospheric nitrogen in solutions which contained no nitrates. Hiltner[72] found in soil inoculated with denitrifying bacteria that the yield was greater than where the soils were sterile. Lipman[73] found in soils containing small amounts of nitrogenous matter that *B. pyocyaneus* and a number of other denitrifying bacteria were able to fix atmospheric nitrogen.

Beijerinck[74] found that a greater fixation of atmospheric nitrogen occurred in solutions which contained small amounts of organic nitrogen, and this finding was later confirmed by Lipman's[75] experiments. Chester[76] has recently proved without a shadow of doubt that a number of species of bacteria common in sewage are, under certain conditions, able to fix large amounts of atmospheric nitrogen. In addition, there is much recent literature concerning the fixation of nitrogen by bacteria in root tubercles, but the indications at present are that these bacteria are all of one species, and that they do not come within the scope of the sewage analyst.

Denitrification. — In the nitrate solution, besides the peptone and the atmospheric nitrogen as sources of nitrogen, we have present the nitrates, and the changes which may take place are more complex and subject to variation. Here we may have, as in the peptone solution, the fixation of atmospheric nitrogen and the conversion of the peptone into ammonia or free nitrogen or both. We may also have the reduction of the nitrates to nitrites, to ammonia, to free nitrogen, and we may have the formation of nitrous and nitric oxides. Furthermore, we may have secondary reactions between the nitrites or the lower oxides of nitrogen and the amino acids and amines. The literature on denitrification is particularly rich, owing to its great significance in agriculture.

As early as 1862, Gopplesröder[77] observed that in rich soils denitrification usually took place. In 1867 Froehde[78] observed that a reduction of nitrates frequently occurred when putrefying organic matter was present. In 1868 Schoenbein[79] noticed that many fungi (bacteria?) were able to reduce nitrates to nitrites, and offered the presence of nitrites in drinking water as direct evidence of the presence of microörganisms. In 1871 Meusel[80] attributed the reduction of nitrates in water to the action of bacteria. Pesci[81] observed that the reduction of nitrates was much more rapid in liquids than in dry or slightly moist material. Gayon and Dupetit[82] in 1882 observed that in river water containing small amounts of nitrates the nitrates were quickly reduced to ammonia. Deherain and Maquenne[83] and Springer[84] attributed the reduction of nitrates to the agency of anaërobic bacteria, which either reduced the nitrates to lower oxides of nitrogen or to free nitrogen. Heræus,[85] in 1886, isolated from water two species which quickly reduced nitrates to nitrites. Blasi and Fravoli,[86] in 1888, studied twenty-seven species which they had isolated from soil, and found that in the majority of instances these species rapidly reduced nitrates to nitrites, and then slowly destroyed the nitrites, although they fail to state what the end-product was. Giltay and Aberson,[87] in 1892, found common in soil and in the atmosphere two organisms, both of which were able to reduce nitrates completely with a liberation of free nitrogen. Eugnow,[88] Burri, Herfeldt and Stutzer,[89] and Schirokokh[90] all isolated and studied species which reduced nitrates. Sewerin[91] studied twenty-nine species, twenty of which were able to reduce nitrates more or less completely. Maasen,[92] in 1902, found that of 109 species of bacteria he examined eighty-five

were able to produce nitrites in solutions containing nitrates. The writer,[93] in a previous paper, reported that of over 5,300 cultures of bacteria isolated at the Experiment Station over 85 per cent. were able to reduce nitrates more or less completely, and of forty-six different species described at that time thirty-five reduced nitrates to nitrites.

Jensen[94] states that denitrifying bacteria are usually present in the excreta from herbivorous animals, but that they are rare in the effluvia of carnivorous animals. Chester[95] shows that denitrification may take place either under aërobic or anaërobic conditions, confirming the results of Stutzer and Maul[96] and of Boname,[97] who found that denitrification was less rapid under aërobic than under anaërobic conditions. On the other hand, Pfeiffer, Franke, and Gotze and Thurmann[98] obtained results which led them to believe that denitrification was more rapid when there was free access of air. Frankland[99] concluded from a study of thirty-two well-known species of water bacteria, more than half of which were able to reduce nitrates to nitrites more or less completely, that the action of these organisms was the same whether they were grown under aërobic or anaërobic conditions.

Stutzer and Jensen[100] showed that a certain amount of organic matter was necessary in solutions for cultures of bacteria to actively reduce nitrates, and the conclusions of these writers have been confirmed by experiments of Kruger[101] and Wood.[102] Jeannel[103] found that the reduction of nitrates was more rapid when carbohydrates were present.

Liberation of Nitrogen from Nitrated Solutions. — There is some experimental evidence to show that nitrogen is liberated from nitrated solutions, and that in some instances this liberation is due to secondary reaction between the amides and amino acids and some of the oxides of nitrogen.

As early as 1867, Dr. Angus Smith[104] observed that a reduction of nitrates accompanied by a loss of nitrogen occurred in decomposing sewage. Lipman[105] found that all of the five cultures which he studied, *Bacillus subtilis*, *B. fluorescens*, *B. megatherium*, *B. pyocyaneus*, and *B. New Jersey*, liberated nitrogen from organic solutions containing nitrates, although one of the cultures failed to reduce nitrates. Gerlach and Vogel[106] isolated from soil and manure a number of species of bacteria which, in solutions in which potassium nitrate was the only source of nitrogen, were able to reduce nitrates to nitrites.

Later the nitrites disappeared and determinations of total nitrogen showed that there was a loss of nitrogen, although no ammonia had been formed during any portion of the experiment. Grimbert[107] found that, while both *B. coli* and *B. typhosus* are able to liberate nitrogen from nitrated solutions, these species do not liberate free nitrogen unless amido compounds are present, and when nitrogen is liberated by these organisms from a nitrated medium, the volume of nitrogen is always about double the amount of nitrogen lost from the nitrates, thus confirming a previous observation of Hugonenq and Doyon,[44] that *B. coli* reduces nitrates, setting free nitrogen and utilizing the oxygen to oxidize carbonaceous matter. Ampolla and Gatino[108] studied an organism which reduced nitrates completely, forming a gas which consisted of 85 per cent. of nitrogen and 15 per cent. of carbon dioxide. These authors also found that denitrification is more rapid in alkaline than in acid solutions, and that relatively small amounts of acid were able to prevent losses of nitrogen. That this does not hold true with the organic acids is shown by the experiments of Schlössing,[109] who established the fact that nitrogen is always liberated when the lactic fermentation of sugars occurs in the presence of nitrates.

Deherain and Maquenne[110] studied the gases evolved during denitrification and found that they contained free nitrogen, carbon dioxide, and nitrous oxide. Gayon and Dupetit[111] observed that nitrogen was evolved during denitrification, and that the presence of organic nitrogen was necessary for this evolution. They were led to believe that the organic nitrogen is decomposed into ammonia and amides, and that the liberation of free nitrogen is the result of secondary reaction between the amido derivatives of the organic matter and the reduction products of the nitrates. By properly controlling the composition of the fermenting solutions they were able to produce a liberation of nitrogen with or without the admixture of nitrous oxide. Ampolla and Ulpianni[112] describe two species which changed nitrates in the presence of organic matter into free nitrogen without the intermediate production of nitrites. Frankland[113] found that although *Bacillus aquatilis* was unable to cause a reduction of nitrates to nitrites, yet there was a considerable loss of nitrates from solutions in which it was cultivated. Burri and Stutzer[21] observed that *B. denitrificans II* was able to liberate about 90 per cent. of the nitric nitrogen from certain nitrated solutions, the remaining nitrogen being rendered insoluble. At the start they found that this organism was aërobic, but after denitrification was once started it was

able to develop under anaërobic conditions, indicating that the organism was able to use the oxygen set free from the nitrates in its own life-cycle.

The foregoing presents a brief and at the same time comprehensive review of the more important literature on bacteriolysis, so far as it appears to be directly applicable to the problems confronting the sewage disposal expert and to the subject-matter of the present paper.

While a number of excellent reviews of different portions of the literature have appeared in the past, nearly all of these, compiled by agricultural bacteriologists, have contained much matter which at present seems to be of no moment in sewage treatment, and have not emphasized the points which are of paramount importance to the practical sanitary expert. The viewpoints of the soil bacteriologist and of the man dealing with the disposal of the sewage of large cities are diametrically opposite, the problem of the former being the conservation of nitrogen and the bringing of that nitrogen to the cultivated field in such a form that it shall be stable and readily assimilated by growing plants, while the latter desires to get rid of the nitrogenous matters as quickly and as cheaply as possible. However deplorable the liberation of nitrogen may be in agriculture and however desirable the assimilation of atmospheric nitrogen, in sewage treatment this same fixation of nitrogen is to be prevented whenever possible, while the liberation of large quantities of organic nitrogen as an inoffensive gas would be of immense advantage.

Discussion of the Experimental Data

In discussing the results obtained from the study of the change in the nitrogen contents of the experimental solutions by the selected cultures, the data has been collected in two tables, No. II showing the progressive change induced by each culture as determined by analyses on successive days, and No. III showing the reduction in the amount of the various nitrogenous constituents and the gain or loss of nitrogen during the entire period of the experiment. In considering the progressive change in the nitrogen contents of the solutions, as shown by the results in Table II, it will simplify matters somewhat to take up the various reactions by types rather than to discuss the phenomena of each culture separately.

Ammonification. — The amount of ammonia produced in the peptone

solution has varied widely with the individual cultures. Of the twenty cultures included in the table, No. 33 showed no ammonification whatever. Five cultures, Nos. 11, 17, 23, 26, and 38, showed only traces of ammonia, *i. e.*, less than 0.5 parts per 100,000, and No. 4 showed only 0.7 of a part. The maximum amount of ammonia produced by any one culture was 18.0 parts, this being recorded for culture No. 10 on the twentieth day. Four cultures, Nos. 10, 13, 16, and 24, produced over 4.0 parts of ammonia. As to the rate of ammonification, after two days' growth none of the cultures showed any traces of ammonia. After four days four cultures had begun to ammonify, these being Nos. 10, 24, 31, and 40. On the sixth day three more cultures, Nos. 18, 22, and 41, had begun to produce ammonia. On the tenth day eleven of the twenty cultures showed ammonia production, cultures Nos. 9, 13, 16, and 29 having come into the fold, and on the thirteenth day two more cultures, Nos. 1 and 7, were added to the list.

Denitrification. — In the reduction of nitrates the various cultures have shown many peculiarities, in some cases a steady decrease in the amount of nitrates being noticed, while with other cultures the increase in the reduction was spasmodic and erratic. Six of the cultures, Nos. 1, 13, 16, 23, 26, and 38, failed to reduce nitrates at any time in the period during which they were under examination, although culture No. 38 produced small amounts of both nitrites and ammonia in the nitrate solution. Four of the cultures, Nos. 4, 10, 11, and 18, reduced all of the nitrates within the period of incubation, while four more, Nos. 7, 9, 17, and 22, reduced over 50 per cent. of the nitrates. As to the rate of denitrification, two of the cultures, Nos. 10 and 31, showed losses of nitrates on the second day. On the fourth day five more cultures showed nitrate reduction, these being Nos. 7, 18, 22, 40, and 41. On the sixth day culture No. 11 showed denitrification, and on the tenth day culture No. 33 began to be active. Four more cultures, Nos. 4, 9, 24, and 29, showed up on the thirteenth day, and by the seventeenth day culture No. 17 had begun to reduce.

Nitrite Production. — As with the reduction of nitrates, the production of nitrites by the various cultures has been subject to considerable variation. Four of the cultures, Nos. 10, 13, 16, and 23, failed to produce nitrites. Of these, culture No. 10 is of special interest, because, although this culture reduced the nitrates completely, the reduction did not go through the nitrite stage. Three of the cultures, Nos. 1, 26, and 33, produced only traces of nitrites, that is, less than 0.5 part, and

culture No. 38 produced less than 1.0 part. Culture No. 38 is especially interesting, because, although the nitrates were not reduced by the culture, nitrites and ammonia were formed in the nitrate solution in small amounts. The results from cultures Nos. 29, 31, and 41 are interesting, as more nitrites were produced than there was loss of nitrate (in solution *B*), and cultures Nos. 29 and 40 showed nitrite production before any reduction of nitrates was noted. These results may be taken as evidence that in the nitrate solution some oxidation or nitrification may have taken place, although in no case were nitrites found in the peptone solution. One of the cultures, No. 11, produced nitrites equivalent to 100 per cent. of the total amount of nitrates reduced, and seven more of the cultures, Nos. 4, 7, 9, 17, 18, 22, and 40, produced nitrites equivalent to 50 per cent. or more of the total amount of nitrates reduced. Of the cultures producing more than 1.0 part of nitrites, Nos. 31 and 41 gave reactions on the second day and No. 40 on the fourth day. On the sixth day cultures Nos. 7, 18, and 22 had begun to produce nitrites actively, and on the tenth day cultures Nos. 9, 11, and 29 were added to the list. Culture No. 4 did not show any great amount of nitrites until the thirteenth day, and cultures Nos. 17 and 24 did not show active nitrite production until the seventeenth day.

Reduction of Nitrates to Ammonia.—The previously discussed functions, the ammonification of peptone, the reduction of nitrates, and the production of nitrites, are functions which can be accurately determined and of which we can speak positively in quoting results. As to the production of ammonia *from the nitrates*, however, we cannot speak so conclusively, owing to the indirect method of determination, *i. e.*, by the subtraction of the ammonia formed in the peptone solution (*A*) from the total amount of ammonia formed in the nitrated peptone solution (*B*), and to the fact that the same culture may not ammonify the peptone in the same ratio in the two solutions; and, while we may draw inferences, our results must always be open to criticism and doubt. Nevertheless, some of the results obtained have apparently been of considerable significance. The estimated amounts of ammonia formed from the nitrates, as shown in Table II, are much more erratic and subject to variation than are the figures of the directly determined functions. Eight of the cultures, Nos. 1, 7, 13, 16, 18, 22, 23, and 29, did not show any apparent production of ammonia from the nitrates. Five of the cultures, Nos. 4, 9, 10, 11, and 24, produced ammonia

TABLE II.—Showing the Progressive Change in the Nitrogen Content of Peptone Solution (*A*) and Nitrated Peptone Solution (*B*) Due to the Growth of Pure Cultures of Bacteria

Culture number.	Days.	Nitrogen—Parts per 100,000.				
		Nitrates, total reduction. Solution *B*.	Nitrites from nitrates. *B*. Direct reading.	Ammonia from		Undetermined nitrogen from nitrates.
				Nitrates. *B-A*.	Peptone. *A*.	
N-1	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.2	0.0
	6	0.0	0.0	0.0	0.2	0.0
	8	0.0	0.0	0.1	0.2	0.0
	10	0.0	0.0	0.2	0.3	0.0
	13	0.0	0.0	0.0	1.0	0.0
	17	0.0	0.1	0.0	2.0	0.0
	20	0.0	0.1	1.7	2.1	0.0
N-4	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.1	0.0
	6	0.0	0.0	0.0	0.1	0.0
	8	0.0	0.0	0.0	0.2	0.0
	10	0.0	0.1	0.2	0.3	0.0
	13	3.0	2.3	0.8	0.6	0.0
	17	6.0	5.5	5.5	0.5	0.0
	20	6.0	5.0	6.9	0.6	0.0
N-7	2	0.8	0.8	0.0	0.1	0.0
	4	1.2	0.9	0.0	0.2	0.3
	6	1.7	1.3	0.0	0.3	0.4
	8	2.2	1.6	0.0	0.5	0.6
	10	2.5	1.8	0.0	0.7	0.7
	13	2.5	1.7	0.0	1.1	0.8
	17	3.0	1.6	0.0	2.0	1.4
	20	3.5	1.6	0.0	2.2	1.9
N-9	2	0.3	0.3	0.0	0.1	0.0
	4	0.4	0.4	0.0	0.2	0.0
	6	0.4	0.4	0.0	0.4	0.0
	8	0.4	0.6	0.0	0.7	0.0
	10	0.5	1.2	0.0	1.0	0.0
	13	1.2	0.6	0.6	0.1	0.0
	17	2.5	1.5	0.0	3.2	1.0
	20	5.3	3.0	1.5	2.3	0.8
N-10	2	1.0	0.0	0.6	0.5	0.4
	4	2.7	0.0	1.0	1.5	1.7
	6	2.7	0.0	1.1	2.4	1.6
	8	2.7	0.0	0.0	2.5	2.7
	10	2.7	0.0	2.6	4.0	0.1
	13	2.7	0.0	1.0	10.0	1.7
	17	2.7	0.0	2.4	7.4	0.3
	20	2.7	0.0	0.0	18.0	2.7
N-11	2	0.2	0.2	0.0	0.0	0.0
	4	0.2	0.2	0.0	0.0	0.0
	6	1.5	0.2	0.0	0.0	1.3
	8	1.7	0.7	0.3	0.0	0.7
	10	1.8	1.5	1.1	0.1	0.0
	13	5.0	3.4	1.2	0.2	0.4
	17	6.0	6.0	3.3	0.2	0.0
	20	6.0	2.8	4.5	0.5	0.0
N-13	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.2	0.0
	6	0.0	0.0	0.0	0.2	0.0
	8	0.0	0.0	0.0	0.3	0.0
	10	0.0	0.0	0.0	1.1	0.0
	13	0.0	0.0	0.0	2.9	0.0
	17	0.0	0.0	0.0	4.5	0.0
	20	0.0	0.0	0.0	4.2	0.0

TABLE II. — Showing the Progressive Change in the Nitrogen Content of Peptone Solution (*A*) and Nitrated Peptone Solution (*B*) Due to the Growth of Pure Cultures of Bacteria. — *Continued*

Culture number.	Days.	Nitrogen — Parts per 100,000.				
		Nitrates, total reduction. Solution *B*.	Nitrites from nitrates. *B*. Direct reading.	Ammonia from		Undetermined nitrogen from nitrates.
				Nitrates. *B-A*.	Peptone. *A*.	
N-16	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.0	0.0
	6	0.0	0.0	0.0	0.5	0.0
	8	0.0	0.0	0.0	1.2	0.0
	10	0.0	0.0	0.0	3.0	0.0
	13	0.0	0.0	0.0	5.5	0.0
	17	0.0	0.0	0.0	4.9	0.0
	20	0.0	0.0	0.0	7.5	0.0
N-17	2	0.1	0.1	0.0	0.0	0.0
	4	0.4	0.4	0.0	0.2	0.0
	6	0.5	0.5	0.1	0.2	0.0
	8	0.6	0.7	0.2	0.2	0.0
	10	0.5	0.7	0.2	0.2	0.0
	13	0.7	0.9	0.7	0.3	0.0
	17	1.6	1.4	2.0	0.2	0.0
	20	2.3	2.2	2.8	0.2	0.0
N-18	2	0.2	0.3	0.0	0.4	0.0
	4	1.5	0.1	0.0	0.9	1.4
	6	2.7	1.7	0.0	1.1	1.0
	8	2.7	1.9	0.0	1.1	0.8
	10	2.7	2.4	0.0	1.2	0.3
	13	2.7	2.0	0.0	2.4	0.7
	17	2.7	2.2	0.0	2.4	0.5
	20	2.7	2.6	0.0	2.2	0.1
N-22	2	0.5	0.2	0.1	0.4	0.2
	4	1.7	0.1	0.2	0.9	1.4
	6	2.0	1.5	0.0	1.3	0.5
	8	2.0	1.7	0.0	1.5	0.3
	10	2.1	1.6	0.1	1.5	0.4
	13	2.1	1.2	0.0	2.8	0.9
	17	2.1	2.0	0.0	2.8	0.1
	20	2.1	1.8	0.0	3.0	0.3
N-23	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.2	0.0
	6	0.0	0.0	0.0	0.2	0.0
	8	0.0	0.0	0.0	0.2	0.0
	10	0.0	0.0	0.0	0.3	0.0
	13	0.0	0.0	0.0	0.4	0.0
	17	0.0	0.0	0.0	0.3	0.0
	20	0.0	0.0	0.0	0.7	0.0
N-24	2	0.5	0.0	1.7	0.8	0.0
	4	0.5	0.0	1.3	1.5	0.0
	6	0.5	0.0	1.7	2.2	0.0
	8	. .	. .	. .	. .	. .
	10	0.5	0.0	1.7	3.7	0.0
	13	2.5	0.1	2.6	4.2	0.0
	17	4.5	1.8	3.8	4.8	0.0
	20	. .	. .	. .	. .	. .
N-26	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.1	0.0
	6	0.0	0.0	0.0	0.2	0.0
	8	. .	. .	. .	. .	. .
	10	0.0	0.0	0.3	0.2	0.0
	13	0.0	0.0	0.3	0.1	0.0
	17	0.0	0.1	0.5	0.2	0.0
	20	. .	. .	. .	. .	. .

TABLE II. — SHOWING THE PROGRESSIVE CHANGE IN THE NITROGEN CONTENT OF PEPTONE SOLUTION (*A*) AND NITRATED PEPTONE SOLUTION (*B*) DUE TO THE GROWTH OF PURE CULTURES OF BACTERIA. — *Concluded*

Culture number.	Days.	NITROGEN — PARTS PER 100,000.				
		Nitrates, total reduction. Solution *B*.	Nitrites from nitrates. *B*. Direct reading.	Ammonia from		Undetermined nitrogen from nitrates.
				Nitrates. *B–A*.	Peptone. *A*.	
N-29	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.1	0.0	0.0
	6	0.0	0.5	0.0	0.8	0.0
	8	. .	. .	. .	. .	. .
	10	0.0	1.8	0.0	1.6	0.0
	13	1.5	4.8	0.0	1.9	0.0
	17	1.5	4.5	0.0	2.7	0.0
	20	. .	. .	. .	. .	. .
N-31	2	2.0	2.6	0.5	0.6	0.0
	4	2.5	4.0	0.5	1.1	0.0
	6	9 0	9.0	1.0	1.5	0.0
	8	. .	. .	. .	. .	. .
	10	9.0	13.0	1.0	1.6	0.0
	13	9.0	7.0	1.4	2.1	0.6
	17	11.0	15.0	1.5	2.4	0.0
	20	. .	. .	. .	. .	. .
N-33	2	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.0	0.0
	6	0.0	0.0	0.0	0.0	0.0
	8	. .	. .	. .	. .	. .
	10	1.5	0.0	0.0	0.0	1.5
	13	1.5	0.1	0.1	0.0	1.3
	17	1.5	0.5	0.6	0.0	0.4
	20	. .	. .	. .	. .	. .
N-38	2	0.0	0.0	0.0	0.1	0.0
	4	0.0	0.0	0.0	0.1	0.0
	6	0.0	0.0	0.0	0.4	0.0
	8	. .	. .	. .	. .	. .
	10	0.0	0.3	0.2	0.4	0.0
	13	0.5	0.7	0.1	0.4	0.0
	17	0.0	0.9	0.7	0.4	0.0
	20	. .	. .	. .	. .	. .
N-40	2	0.0	0.8	0.0	0.6	0.0
	4	2.5	1.6	0.0	1.0	0.9
	6	2.5	2.0	0.1	1.1	0.4
	8	. .	. .	. .	. .	. .
	10	2.5	2.4	0.2	1.3	0.0
	13	2.5	1.8	0.2	1.4	0.5
	17	2.5	2.2	0.4	1.5	0.0
	20	. .	. .	. .	. .	. .
N-41	2	0.5	1.5	0.0	0·5	0.0
	4	2.5	2.4	0.0	0.8	0.1
	6	2.5	3.2	0.0	1.0	0.0
	8	. .	. .	. .	. .	. .
	10	2.5	3.5	0.5	1.0	0.0
	13	2.5	5.5	0.4	1.1	0.0
	17	2.5	4.0	0.3	1.8	0.0
	20	. .	. .	. .	. .	. .

equivalent to more than 50 per cent. of the total amount of nitrates reduced. Cultures Nos. 4, 17, and 24 produced more ammonia during certain periods of the time that they were under examination than was the total amount of nitrates reduced, and one culture, No. 38, pro-

duced ammonia, although no reduction of the nitrates occurred. The cause of this overproduction of ammonia is difficult to explain. It may have been due to secondary reactions between the nitrites, or other oxides of nitrogen, and the amides or amido acids; it may have been due to the direct fixation of atmospheric nitrogen in the form of ammonia; and it may have been due to an invigorating action of the nitrates on the bacteria themselves, causing them to break down the peptone more completely in the solution containing nitrates than they did in the plain peptone solution. Five of the cultures, Nos. 26, 33, 38, 40, and 41, produced less that 1.0 part of ammonia; four of the cultures, Nos. 9, 10, 17, and 31, produced between 1.0 and 3.0 parts of ammonia; and three of the cultures, Nos. 4, 11, and 24, produced more than 3.0 parts of ammonia.

Undetermined Nitrogen from Nitrates. — The figures given in this column, as previously explained, are of very doubtful significance, including as they do the sum of all the errors in the other determinations. Nevertheless, the results are more or less significant as indicating whether other oxides of nitrogen than nitrites had been formed, which oxides would not be determined by the analytical methods employed, and also as furnishing additional evidence as to the liberation of nitrogen from solutions containing nitrates. Eleven of the cultures did not show losses of nitrates which could not be accounted for either as nitrites or ammonia, while six of the cultures, Nos. 7, 10, 11, 18, 22, and 23, showed losses, or undetermined nitrogen, amounting to over 50 per cent. of the total amount of nitrates reduced. With cultures Nos. 11, 18, 22, 23, and 40 the largest amounts of undetermined nitrogen occurred during the earlier or intermediate portions of the period of incubation, these amounts decreasing or entirely disappearing towards the end of the incubation period. This would indicate oxides of nitrogen, or, at least, that the nitrogen was in some form which was not determinable, but which was afterwards changed to a form which we were able to determine. With cultures Nos. 11, 33, and 40 the indications are that these losses occurred between the nitrites and ammonia. With cultures Nos. 18 and 22, however, the fact that a very rapid reduction of nitrates occurred, a large percentage of which could not be accounted for either as nitrites or ammonia, but which percentage was later reduced as the nitrites increased, would appear to indicate that some intermediate product between the nitrates and nitrites has been formed. Such a product, so far as we have been able to discover, has never been noted

by previous observers, and, if the results are not in error, is of much interest. In addition to these cultures, three others, Nos. 7, 9, and 31, showed losses or undetermined nitrogen which it would appear was liberated as elementary nitrogen. This is especially marked with culture No. 7, in which the loss of nitrogen increased in direct ratio with the time of incubation.

Gain or Loss of Nitrogen. — On all of the cultures which were studied, besides the daily tests for nitrates, nitrites, and ammonia, tests were made for total organic nitrogen in the solutions by the Kjeldahl method at the beginning and end of the period of incubation. By the use of these Kjeldahl values, together with the values for ammonia, nitrites, and nitrates, assuming that none of the nitrogen is present in forms which would not be determined by these methods, we have been able to compute the gain or loss of nitrogen in the solutions, and to compare the reduction of organic nitrogen with the reduction of nitric nitrogen.

Of the results obtained with the thirty cultures which are included in Table III, eighteen of the cultures showed a loss of nitrogen in the peptone solution and twelve of the cultures showed a gain. In the solution containing nitrates, sixteen of the cultures showed a loss of nitrogen and thirteen showed a gain. Nineteen of the cultures agreed as to gain or loss of nitrogen as determined in the two solutions, one of the cultures showed no change in the nitrate solution, and ten of the cultures showed a gain or loss in the peptone solution when the reverse was true in the nitrate solution. With seven of these ten cultures the gain or loss of nitrogen in one solution or the other was less than 0.5 part per 100,000 of nitrogen, this being the limit of error of the Kjeldahl method as determined by duplicate analyses of all the cultures. One culture showed a gain or loss of exactly 0.5 per cent., and this may be included with the other seven, leaving only two cultures in which there was an appreciable discrepancy in the two solutions, these being culture No. 9, which showed a gain of 1.2 parts in the peptone solution and a loss of 1.8 parts in the nitrate solution, and culture No. 34, which showed a loss of 1.7 parts in the peptone solution and a gain of 12.1 parts in the nitrate solution.

The maximum gain in nitrogen in the peptone solution was made by culture No. 10, which gained 12.0 parts nitrogen, and the maximum gain in the nitrate solution was by culture No. 34, which gained 12.1 parts nitrogen. The greatest losses were made by culture No. 16,

which lost 5.0 parts of nitrogen in the peptone solution, and by culture No. 32, which lost 6.6 parts of nitrogen in the nitrate solution. Assuming that the error of the methods is 0.5 part per 100,000, twenty-two of the thirty cultures gained or lost more than this amount in the peptone solution, and twenty-three gained or lost more than this amount in the nitrate solution. Comparing the reduction of organic nitrogen by the same cultures in the two solutions, with twenty cultures a greater reduction occurred in the nitrate solution than in the peptone solution, either through increased activity of the bacteria in the presence of nitrates, or through secondary reactions between the decomposition products of the nitrates and organic matter. With seven of the cultures the reduction of organic nitrogen in the nitrate solution was less than in the peptone solution, and this may possibly be ascribed to the slight deterrent action of nitrates on certain cultures, which has been mentioned before. Of the cultures which gained nitrogen in the nitrate solution, nine were able to reduce nitrates and four did not reduce nitrates, while of the cultures which showed a loss of total nitrogen in the nitrate solution, eleven reduced nitrates and five did not.

Comparing the reduction of organic nitrogen in the nitrate solution with the reduction of nitric nitrogen, we find that of the twenty-four cultures which showed a reduction of organic nitrogen of 0.5 part or more seven failed to reduce nitrates, while of the six cultures which did not cause any material reduction in the organic nitrogen three were able to produce a decided reduction of the nitric nitrogen. The figures showing the reduction of organic nitrogen and the reduction of nitric nitrogen, together with the amount of nitrogen determined by the various methods and the probable gain or loss in the nitrogen contents of the solutions, are shown in the following table:—

TABLE III. — Showing the Gain or Loss of Nitrogen as Computed from Kjeldahl Values and Determinations of Nitrates, Nitrites, and Ammonia

(Parts per 100,000)

Culture.	Peptone Solution (*A*).			Nitrate Solution (*B*).				
	Reduction of organic nitrogen.	Determined as ammonia.	+ = Gain. − = Loss.	Reduction of organic nitrogen.	Reduction of nitric nitrogen.	Total reduction of *initial* nitrogen.	Determined as nitrites and ammonia.	+ = Gain. − = Loss.
1	1.6	2.1	+0.5	2.2	0	2.2	3.9	+1.7
2	2.4	1.1	−1.3	0	0	0	1.0	+1.0
4	0	0.6	+0.6	4.5	6.0	10.5	12.5	+2.0
6	6.8	1.8	−5.0	0	1.0	1.0	0.9	−0.1
7	4.5	2.2	−2.3	3.2	3.5	6.7	3.4	−3.3
8	0	2.3	+2.3	0	2.6	2.6	3.1	+0.5
9	1.1	2.3	+1.2	2.8	5.3	8.1	6.8	−1.3
10	6.0	18.0	+12.0	8.3	2.7	11.0	12.0	+1.0
11	0.1	0.5	+0.4	4.5	6.0	10.5	7.8	−2.7
12	2.1	3.8	+1.7	2.3	0	2.3	1.9	−0.4
13	3.3	4.2	+0.9	1.4	0	1.4	1.4	0
16	3.5	7.4	+4.0	0.4	0	0.4	1.0	+0.6
17	3.0	0.2	−2.8	3.0	2.3	5.3	5.2	−0.1
18	1.8	2.2	+0.4	2.4	2.7	5.1	4.4	−0.7
22	3.1	3.0	−0.1	2.3	2.1	4.4	4.4	0
23	0	0.7	+0.7	0.1	0	0.1	0.5	+0.4
24	6.2	4.8	−1.4	8.4	4.5	12.9	10.4	−2.5
25	0.5	0.3	−0.2	4.9	9.0	13.9	17.7	+3.8
26	0.4	0.2	−0.2	1.6	0	1.6	0.8	−0.8
27	1.5	0.9	−0.6	2.5	0	2.5	0.6	−1.9
29	2.3	2.7	+0.4	3.2	1.5	4.7	6.4	+1.7
30	0.5	0.3	−0.2	0	2.5	2.5	4.7	+2.2
31	3.2	2.4	−0.8	5.5	11.0	16.5	18.9	+2.4
32	5.3	4.8	−0.5	9.0	1.5	10.5	3.9	−6.6
33	2.0	0	−2.0	2.2	1.5	3.7	1.1	−2.6
34	1.7	0	−1.7	4.1	2.5	6.6	18.7	+12.1
36	1.1	0.4	−0.7	1.5	0	1.5	0.6	−0.9
38	0.6	0.4	−0.2	2.1	0	2.1	2.0	−0.1
40	2.9	1.5	−1.4	2.8	2.5	5.3	4.1	−1.2
41	2.3	1.8	−0.5	3.1	2.5	5.6	6.1	+0.5

The Distribution of Ammonifying and Denitrifying Bacteria in Sewage and Effluents from Sewage Filters, and the Relation of Peptonization to Other Biochemical Functions. — Of the biochemical functions of bacteria concerned in sewage disposal, the most important, and the ones which can be most accurately determined, are the power to liquefy insoluble organic matter and the power to break down the soluble proteids, peptones, albumoses, etc., into ammonia. These two reactions are the first essentials, and are closely seconded in importance by those reactions by which this ammonia is converted into some stable product such as nitrates, in which form it is at least inoffensive. Denitrification, while in a measure a retrograde process, undoubtedly does occur to a greater or less extent in all biological methods of sewage treatment, and it is an open question whether the secondary reactions between the reduction products of the nitrates and the intermediate products of peptonization are not of more importance, and more worthy of careful study and control, than has generally been thought to be the case. While these changes may be purely chemical in their nature, or may be due to the action of enzymes, they are brought about directly or indirectly by the action of bacteria, and for this reason some figures as to the relative numbers of bacteria in sewage and in the effluents from some of the various types of sewage filters may properly be inserted in a paper of this kind.

During a study of the biochemical functions of the bacteria concerned in sewage purification previously reported, determinations of the ammonifying and denitrifying powers of over three hundred cultures of bacteria were made, and in addition tests were made for the amount of liquefaction which many of these cultures were able to produce in gelatin. The solutions and methods of procedure for the nitrogen tests were the same as previously described in this paper, a standard period of incubation of seven days at 20° C. being employed. The method of making the quantitative gelatin tests was as follows: Test tubes of a uniform bore of 10 mm. were filled to a depth of 100 mm. with standard beef peptone gelatin, and the entire surface of the gelatin was inoculated with the culture. Any liquefaction which occurs must proceed straight down from the surface of the gelatin, and the depth of this liquefaction in millimeters in a given time is a numerical measure of the rate or amount of liquefaction.

The cultures were selected from the colonies on the gelatin plates in such a way as to represent as closely as possible all of the kinds of

bacteria in the samples, that is, all of the kinds of bacteria which would be shown by the ordinary plate method. From the data thus accumulated it has been possible to compute the percentage of the total number of bacteria in the individual samples which possessed these functions, and by averaging the percentages in the various samples to determine approximately the percentage of the total bacteria in samples of different kinds which were able to produce ammonia in peptone solution and to reduce nitrates. From these figures it appears that a considerable majority of the bacteria in sewage and in the effluents and material from sewage filters are possessors of both of these functions. The results are shown in the following table:—

TABLE IV.—Showing Percentage of Ammonifying and Denitrifying Bacteria in Sewage and the Effluents from Sewage Filters

Source.	Number of samples.	Percentage of Total Bacteria which	
		Ammonify peptone.	Reduce nitrates.
Sewage	3	90	70
Septic sewage	6	56	59
Effluent contact filters	3	60	61
Effluent trickling filters	4	59	71
Effluent sand filters	15	70	70
Sand from sewage filters	3	90	70

The tests for gelatin liquefaction were made on 157 of the beforementioned cultures, and a comparison of the results of these tests with the various changes in the nitrogen contents of the test solutions enables us to trace in a general way the relation between the peptonizing power as represented by the amount of liquefaction of gelatin and the denitrifying and ammonifying powers. These results have been grouped in Table V according to their liquefying power. Comparing the results obtained with cultures which liquefied with those which did not liquefy, we find that the liquefiers have an average ammonifying power nearly twice as great as the non-liquefiers, that they have a denitrifying power about three times as great as shown by the production of nitrites. In each group of cultures, both liquefying and non-liquefying, we find some which cause large changes in the nitrogen contents and others which

TABLE V.—SHOWING RELATION BETWEEN LIQUEFYING POWER AND DENITRIFYING AND AMMONIFYING POWER

	Cultures which did not liquefy gelatin.	Cultures which liquefy gelatin.	Liquefying power between 1 and 10.	Liquefying power between 11 and 20.	Liquefying power between 21 and 30.	Liquefying power between 31 and 40.	Liquefying power over 40.
Average liquefaction	. .	. .	6	15	24	35	49
Nitrate reduction, Average	1.8	5.3	3.1	5.2	6.2	6.8	6.9
Maximum	7.0	9.6	8.7	9.3	9.3	. .	9.6
Minimum	0.0	0.0	0.0	0.0	0.0	. .	2.0
Per cent. of cultures did not reduce nitrates	30	8	29	3	20	. .	0
Nitrite production, Average	1.6	6.1	3.5	6.5	7.7	0	6.5
Maximum	11.0	12.0	11.0	12.0	11.0	. .	11.0
Minimum	0.0	0.0	0.0	0.0	0.0	. .	0.0
Per cent. of cultures did not produce nitrites	32	15	35	8	20	. .	14
Ammonification of peptone, Average	0.4	0.7	1.1	1.8	1.4	0.6	1.4
Maximum	1.9	5.2	3.2	5.2	2.1	. .	4.5
Minimum	0.0	0.0	0.0	0.0	0.0	. .	0.1
Per cent. of cultures did not produce ammonia from peptone	32	2	6	0	10	. .	0
Reduced nitric nitrogen not determined as nitrites and ammonia . . . Average	0.7	1.2	0.3	0.2	0.1	5.3	1.1
Maximum	4.6	5.6	2.4	1.8	0.8	. .	5.6
Minimum	0.0	0.0	0.0	0.0	0.0	. .	0.0
Per cent. of cultures which did not show undeterminable nitrogen	59	45	76	27	80	. .	62
Number of cultures	44	113	17	64	10	1	21

cause no change whatever. A study of the individual analyses reveals, however, that while 30 per cent. of the *non-liquefiers* were unable to reduce nitrates, only 8 per cent. of the *liquefying* cultures failed in that function. Again, 32 per cent. of the *non-liquefying* cultures did not produce nitrites in the nitrate solution, and the same percentage of cultures failed to show any ammonia production in the peptone solution. On the other hand, the number of *liquefying* cultures which failed to produce nitrites was 15 per cent., or less than one-half as many, and the percentage of cultures which failed to break down peptone into ammonia was only 2 per cent., or one-eighth as many as in the case of the non-liquefying cultures. In other words, as shown by the amount of change and by the percentage of cultures reacting, the liquefying cultures are much more active in causing changes in the form of the nitrogenous ingredients of the solution than are the non-liquefying cultures; but the opinion that bacteria which are able to peptonize organic matter *invariably* produce ammonia, and *usually* reduce nitrates, does

not hold true in this instance. The figures showing the average amount of nitrogen lost from nitrates, which was not determined as nitrites or ammonia, also appear to follow the same rule as above stated, although the results are of doubtful significance for reasons which have been previously discussed. Comparing the relative liquefying power with the other functions, we find that as this power increased the power to reduce nitrates also steadily increased. The relation between the increase in the liquefying power and the nitrite production and the ammonification of peptone, however, is less marked. It is probable, however, that with a more extended study, covering a larger number of cultures, the ratio between these functions would be more uniform.

Conclusions

With the advent of the various biological methods of sewage disposal, in which the activity of various classes of bacteria have to be carefully controlled in order to accomplish the desired end, a knowledge of the various biochemical reactions taking place and of the bacteria which produce these changes becomes necessary. Of the various changes occurring in the sewage during treatment, the one which forms our main problem is the change of the nitrogenous matter from a highly objectionable form in which it is present into a non-putrescible and inoffensive form, since in the process of changing the form of the nitrogen contents the carbonaceous matter is also converted into simple elementary compounds. Consequently the problem narrows down to a study of the bacteria causing changes in the nitrogenous matter, and since the study of these bacteria under natural conditions, *i. e.*, in the sewage and in the filters, surrounded as they are by other types of bacteria and under conditions which are constantly changing, is beset with difficulties, it becomes necessary to study these bacteria in pure culture and under constant conditions, in order to acquire data sufficiently exact to be used in an analysis of the more complex problems such as occur in actual practice. The present paper is a portion of a more extended investigation into the types of bacteria normally present in sewage and the effluents of sewage disposal systems and their rôle in the causation of the biochemical reactions occurring during the processes of treatment, and it has to deal with the specific changes which representative types of bacteria in pure culture may produce in solutions containing nitrogen in forms

more or less common in sewage during its purification. Thirty cultures of bacteria, common in sewage and the effluents from sewage filters, have been studied carefully to determine the character and amount of change brought about by their action on peptone and nitrates.

From the results obtained in this study it becomes possible to state definitely that bacteria common in sewage purification are able to produce ammonia from organic matter, to reduce nitrates to nitrites, to ammonia, and probably to elementary nitrogen, to liberate nitrogen from solutions of organic matter either with or without the presence of nitrates or their reduction products, and also to fix atmospheric nitrogen under the same conditions — all of which reactions have been noted by other observers, but about which there has been more or less controversy. Many sewage bacteria probably also produce the lower oxides of nitrogen as reduction products of nitrates, which oxides may play an important part in the further decomposition of the organic matter in solution, either through catalytic action or by direct chemical reaction. Furthermore, certain of these bacteria may perhaps produce an oxide, or at least a compound of nitrogen intermediate between nitrates and nitrites, which has apparently not been noted hitherto.

The amount of ammonia produced by the different cultures has ranged from none to 18.0 parts per 100,000, and the rate of ammonification has varied considerably, some of the cultures reacting as early as the fourth day, while other cultures, which eventually reacted strongly, did not begin to ammonify until after periods of ten to fourteen days. Similar phenomena have been noted with regard to the reaction of the cultures on nitrates. Some have reduced the nitrates rapidly and completely, some have denitrified slowly, some have reacted only after a considerable time of incubation, and others have caused no change. The character of the reduction products, both as regards amount and rate of formation, has also been interesting. Some cultures have been able to reduce the nitrates to nitrites, ammonia, and elementary nitrogen continuously from the start, while with other cultures the reduction to these various bodies has occurred consecutively, and with still others one or another of the reduction products has not occurred during the period over which the examination of the cultures extended. In a few instances nitrites have been produced in quantities far greater than the amount of nitrates, and, if the results are not in error, this can be explained only on the supposition that a direct oxida-

tion or nitrification of the organic material has occurred, caused either by bacterial action or by some undetermined secondary reaction.

Regarding the distribution of ammonifying and denitrifying bacteria in sewage and the effluents from sewage filters, based on a study of the biochemical functions of over three hundred representative cultures from a variety of samples, it may be said that a majority of the bacteria from these sources, which are determinable by the ordinary plate methods using gelatin as a culture medium, reduce nitrates and decompose peptone into ammonia, although these two functions are not always present in the same species. By the use of quantitative tests for the amount of liquefaction produced in gelatin by over 150 of these cultures, we have been able to determine approximately the relation between the peptonizing power, or power to liquefy insoluble organic matter, and the ammonifying and denitrifying powers of sewage bacteria. We find that while many non-liquefying bacteria are able to reduce nitrates or to ammonify peptone or to do both, and many liquefying bacteria do not possess these functions, nevertheless, in a large majority of cases, the possession of the first function means possession of one and usually both of the last two functions, and the average amount of change produced in the nitrogenous matter in solution is much greater with peptonizing bacteria than with those which are unable to liquefy gelatin. Furthermore, an increase in the liquefying power appears, as a rule, to be correlated with increased ability to reduce nitrates and to ammonify peptone.

When we consider that, in addition to further study of the various problems indicated herein with individual species, we have yet to take up the study of *symbiosis*, the action of not one or two types of bacteria but of many, with the complicated series of secondary reactions between the various biochemical products which would result, we can readily see that, while interesting and instructive in themselves, the studies embodied in this paper are only a beginning and a slight step in the direction of a better general understanding of the biochemistry of that important problem, the economic and sanitary disposal of the waste products of the human body.

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CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE INTERPRETATION OF A SEWAGE ANALYSIS

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IT is often the case that analytical data express to the mind of the analyst the direct information desired, but at times there are cases in which such figures convey no useful information until they are examined in the light of past experience. For example, in an assay of a gold ore the results require no explanation, but the results of a steel analysis convey to the lay mind only the idea that there were present in the steel certain very small amounts of sulphur, carbon, phosphorus, etc. To the expert, however, these figures of the steel analysis stand clearly and definitely for certain marked properties in the steel.

This expression of analytical data in terms of physical or other properties of the substances analyzed is called an interpretation of an analysis.

In the case of sewage there are, unfortunately, no well-marked physical characteristics such as are found in steel with which our analytical data may be compared. The interpretation of a sewage analysis is largely a matter of experience on the part of the analyst, or of reference to other analyses for the sake of comparison, rather than any concrete reference to definite properties. Nevertheless when sewages are spoken of as "strong domestic," or "typical city," it is doubtful if any analyst could, from these descriptions, satisfactorily reconstruct the essential features of the original analyses.

In view of the fact that important steps are being taken just now toward standardizing and unifying our methods of analysis, it has seemed to the writer that a brief discussion of our present knowledge of the chemistry of sewage, so far as it relates to the routine analytical

procedure, might not be out of place. To attempt to place the interpretation of a sewage analysis upon the same plane as that of a steel analysis would, of course, be out of the question. It would seem, however, that we have already at hand sufficient analytical data to warrant us in an attempt at correlating this material with the more important variable characteristics of the sewage. It will be necessary first to define these characteristics, keeping in mind the fact that they must be, first, variable and correlated with the analytical data, and, second, of sufficient importance in the ultimate problem of sewage treatment to warrant their study.

These characteristics in a sewage are three in number: the physical property of concentration; the chemical property of composition; and the biological property, which I will call condition.

First in importance is the concentration of the sewage, or, more accurately, of the dissolved and suspended matters in the sewage. By this factor one does not mean merely the concentration as determined by the total solids. For a thorough understanding of the processes of sewage purification the concentration of the organic nitrogen, organic carbon, fats and fatty bodies, and, to a lesser degree, of the various mineral constituents should be known.

Hardly second in importance is the chemical characteristic or composition of the sewage. Here I would eliminate the idea of mere concentration and confine the thought to the actual composition of the solid material. A thorough study of the composition of a sewage would necessarily include complete determinations of the various organic and inorganic substances present. While such analyses would doubtless be of considerable value in enabling us to understand the reactions involved in purification, yet it is doubtful if our increased knowledge would be at all commensurate with the time and labor involved. By a suitable comparison of the concentration values previously mentioned, however, it may be possible to distinguish between certain types of sewage, such as purely domestic sewage, street washings, and factory and other industrial wastes, and, in the case of a sewage of a mixed and variable type, to describe somewhat roughly its actual composition. Obviously this is a matter requiring careful study in attempting any new purification work.

As a first type for such comparison we may study a number of purely domestic sewages. Such sewages will differ widely in the matter of concentration, but in the relative amounts of nitrogen, carbon,

and chlorine they might all be expected to agree within fairly close limits. Variation in these relative numbers would then in any given case denote a variation from the domestic type.

Let us take as an example an actual case. The ratio between the total nitrogen and the chlorine in domestic sewages, as will be shown later, is approximately unity. But at certain times this ratio, in the case of the Boston sewage, may reach as low a figure as one to one hundred, from the backing up of sea water through leaking tide gates. Now if it may be assumed that the normal chlorine value of the sewage in Boston is also equal to the nitrogen, then with the known composition of sea water a simple calculation will show the amount of sea water in the Boston sewage. It is not intended that in ordinary cases the analyst shall attempt in this way to calculate the actual amount of street washings, or other material which has entered the sewage in question, but it is believed that by the use of these composition factors sewages may be classified and compared with each other as to the probable effect upon them of purification treatment.

The third important characteristic of a sewage I have called its condition. By the condition of a sewage I would denote what we variously call its age, freshness, or septicity. But condition as here used is a much more definite property than this, and cannot be expressed as a function of the time alone. Condition is a product of at least three prime factors and of many other minor ones. The three most important are age, temperature, and the number and character of organisms present. Among the other factors may be mentioned the degree of physical disintegration, opportunity for aëration, the presence of germicidal substances, and doubtless many unknown conditions. It will thus become apparent that the mere statement of the age of a sewage, as of a septic sewage, for example, will throw very little light upon its true condition. In attempting to establish condition factors we shall deal not alone with the unvarying constituents, such as the total nitrogen and the total carbon, but with the various forms in which the nitrogen, for example, may occur, and their transformations from one to the other through the activities of the microörganisms or by spontaneous chemical action.

Having now defined the three characteristic properties of a sewage in terms of which we shall attempt to interpret our analytical data, let us examine in some detail our ordinary analytical procedure and see what significance the results have in terms of these properties.

Nitrogen

Nitrogen is determined in four forms, namely, as organic nitrogen, ammoniacal nitrogen, and the nitrogen of nitrous and nitric acids. The two latter forms, containing oxygen, are chiefly significant for that reason, and will be discussed under the head of oxygen.

The Organic Nitrogen. — This constituent as determined by the Kjeldahl process is the most valuable of the concentration factors. Nitrogenous organic matter is, *par excellence*, the substance in sewage requiring purification. Its accurate determination is therefore of first importance in a sewage analysis. In addition to its use as a concentration factor the organic nitrogen figure may be usefully combined with other figures to express ratios showing condition and composition.

The Albuminoid Ammonia. — On the question of the value of the albuminoid ammonia figure as an additional aid in fixing the condition of a sewage little need be said. Clark (1904) has published what is perhaps the most thorough study yet made of this question. By averaging a large number of results from similar samples, and from these averages calculating the ratios of the albuminoid ammonia to the organic nitrogen, he obtained somewhat different ratios for the different conditions of the sewage. The individual deviations from these average ratios in any one group are, however, so great as to entirely mask any significance which these ratios may have. The fact that distinctive ratios can be brought out by averaging would seem to indicate that such figures, if accurately determined, might have considerable value, but that the inaccuracies inherent in the Wanklyn process are sufficient to make the individual determination of little value. Obviously the albuminoid ammonia has no value as a concentration factor.

Free Ammonia. — The nitrogen occurring in the form of ammonium hydrate or of ammonium salts is called "nitrogen as free ammonia." The determination, as usually carried out by distillation from alkaline solution, gives results on sewage which are considerably in excess of the true value as thus defined. This excess is due to the breaking down of unstable nitrogenous material. The German procedure of direct nesslerization, after clarification of the sewage, yields results which are much nearer the truth. There is indeed a slight loss due to adsorption of the ammonia by the precipitate, but by proper manipulation this loss may be reduced to a negligible quantity. Since most of our present data have been obtained by the distillation method, the discussion which follows will consider only such results, although the writer is convinced

that much more constant and significant ratios could be obtained from the figures if they had been obtained by the direct method.

In a very fresh domestic sewage the ratio of the ammoniacal nitrogen to the organic nitrogen is usually about one to two. This applies only to sewage from a small sewer running swiftly. In the larger intercepting sewers of our cities this ratio will be, as a rule, very close to unity. At the other extreme, an old septic sewage in warm weather may show a ratio as high as seven to one. In calculating the ratio in this case allowance must be made for the fact that sedimentation is taking place. The organic nitrogen value to be used in the ratio is not the actual value found, but should be calculated on the assumption that the total nitrogen — organic plus ammoniacal — has not undergone any diminution during the treatment, an assumption sufficiently exact for this purpose. This total nitrogen value, then, should be taken from the unsedimented sewage. Between these two extremes will be found the ratios for ordinary sewages. The rate of change does not seem to be proportional to the time. The ordinary staling of a sewage is not accompanied by a marked rise in the ratio, while in the later stages of active purification a rapid increase is noted.

This ratio is obviously a factor changing with the age of the sewage. The rate of such a change will be affected by the temperature of the sewage, and will also depend upon the number and nature of organisms present. In a septic tank, for example, the change will take place much more rapidly than during the movement of the sewage through the sewer.

No further experimental proof of the fact of the increase of this ratio with age is needed, for it is a matter of common knowledge. As an illustration of the application of this factor in actual practice, the following analyses of Boston sewage at different seasons are given. This sewage is for the major part less than an hour old. The analyses show the effect upon this condition factor of varying temperature, other things being practically constant.

TABLE I. — SHOWING THE EFFECT OF THE TEMPERATURE UPON THE RATIO OF THE AMMONIACAL TO THE TOTAL NITROGEN

Month.	Average temperature.	Number of determinations.	Ratio of Ammoniacal to Organic Nitrogen.		
			Mean.	Maximum.	Minimum.
July	71	8	1.70	3.35	1.44
September . .	65	8	1.08	1.38	0.79
January	47	10	0.82	1.22	0.47

The value of some such a condition factor in discussing and comparing septic sewages will be readily apparent. The usual method of describing such sewages by age only obviously omits the other important factor — temperature — not to mention possible differences in the number and kinds of bacteria originally present. In describing sewages which have not been subjected to septic treatment, not much has hitherto been attempted. Such terms as fresh and stale sewage have been used without any very sharp definitions. The application of condition factors such as have been described and of which other examples will be given will, it is believed, greatly facilitate our descriptions and even clear our conceptions of these matters.

A New Nitrogen Factor. — The application of the nitrogen analytical data to the question of composition as used in this paper still remains to be worked out. Our data so far do not give us any information as to the ease or difficulty of purifying our nitrogenous matter nor of the stability or non-stability of the nitrogenous matter in an effluent; in other words, we know nothing of the *kind* of nitrogenous matter we are dealing with. In the writer's view these two things are identical, that is, a stable effluent would be difficult, and an unstable one easy of further purification. Furthermore, it is believed that the ability of the nitrogenous matter to hydrolyze is a measure of its non-stability or of its ease of purification. Upon this principle the writer is working out the details of a new nitrogen factor which shall be the desired composition factor. Such a factor is of special value in the analysis of effluents, and, it is hoped, may be fully discussed in the second part of this paper, which will deal more especially with the question of effluents.

Carbon

Our knowledge of the carbon in sewage through our analytical results is meagre indeed. The oxygen-consumed test is a measure of the carbonaceous matter present; unfortunately it is also a measure of the nitrites, ferrous salts, part of the chlorine, and doubtless of many other substances at present unknown to us. Add to this the fact that almost every laboratory has its own method of making the determination, and two things become apparent: first, that the results of the different laboratories are not at all comparable, and, second, that the best of the results have but little real value in the interpretation of an analysis. The arguments which have been used for the accurate

determination of the total nitrogen apply with hardly less force to the question of total carbon. The oxygen consumed stands in the same relation to the total carbon as the albuminoid ammonia to the total nitrogen. But the present conditions are much more unsatisfactory in the former case, for the amount of carbon represented is only 2 or 3 per cent. of the total carbon, while the albuminoid ammonia gives one-third or more of the organic nitrogen. What is true of the variable ratio existing between the albuminoid ammonia and the total nitrogen is doubtless equally true as between the oxygen consumed and the total carbon. Hence the oxygen-consumed figures have no value as concentration factors, and, while they may be combined with the total nitrogen figures to form composition ratios, the results are only rough and are not independent of the condition, as composition factors should be. For example, the ratio of the total carbon to the total nitrogen would be an ideal composition factor, since the condition of the sewage would have but slight influence upon it; but the ratio of the oxygen consumed to the total nitrogen will vary with the condition, and hence is not a satisfactory composition factor. It is possible, however, to use this rough factor to distinguish between purely domestic sewage on the one hand and on the other the same sewage mixed with a considerable volume of street washings or of factory wastes from such a process as tanning. Taking the oxygen-consumed figures as determined by the Kubel hot-acid method, with two minutes' boiling we find in a domestic sewage which is reasonably fresh that the oxygen-consumed values are roughly about 50 per cent. greater than the total nitrogen values. Immediately after a heavy shower this value will increase to three or four times the nitrogen figure. The fact must be emphasized, however, that by mere aging of the sewage the same change in this ratio may be brought about.

Since we have but one carbon figure in our analysis, no condition factor based upon carbon alone has been yet developed, although the comparison of values obtained with and without heating seems promising. The change suggested above, while an important correction to the composition factor, is too variable and untrustworthy in its nature to be of any service in denoting condition from the carbon standpoint.

Oxygen

In any ultimate study of processes of sewage purification, either from the point of view of chemical energetics or of biological metabolism, the oxygen of the organic matter must needs be taken into account. Our present state of knowledge, however, does not warrant any such difficult determination as that of the oxygen of the organic substances, and in the present discussion that oxygen will be left entirely out of consideration. There remain, then, the oxygen which is dissolved in the sewage and that which is present in the form of mineral salts, notably as nitrites and as nitrates. Obviously the oxygen thus present has no relation to the concentration of the sewage, and its incidental and brief occurrence can be of no service in fixing the composition. Oxygen is then of importance only as a condition factor. Its importance in this rôle is so great that its determination becomes one of the most important in our scheme of analysis. In the discussion of the free ammonia-organic nitrogen ratio as a condition factor, it was stated that the increase in this ratio proceeded slowly at first. It is true that even in warm weather sewage may be as old as fifteen hours with but slight indication of the fact from this ratio. When putrefaction once sets in the ammonia ratio is important, but up to that time we must rely entirely upon the oxygen values. Fortunately these are easily determined, and are thoroughly indicative of the condition in the earlier stages. The free dissolved oxygen and the nitrites and nitrates probably enter the sewage with the domestic water, although in cold weather the production of nitrates undoubtedly takes place in the sewage. From that time forward, except under very peculiar circumstances, the tendency is towards the redistribution of this oxygen by the bacteria and their products. The rate of change of the oxygen is therefore a measure of the activity of those bacterial processes which are taking place within the sewage, and which by definition are altering its condition.

There is some reason to believe that by interaction between the nitrites and certain decomposition products of the sewage, still ultimately due to the bacteria, a certain amount of the nitrites are consumed by direct chemical reaction. Under such extremely anaërobic conditions as are found in the septic tank, other salts, such as the sulphates and phosphates, are likewise reduced. So sensitive is this oxygen test for condition that in the case of the Boston sewage col-

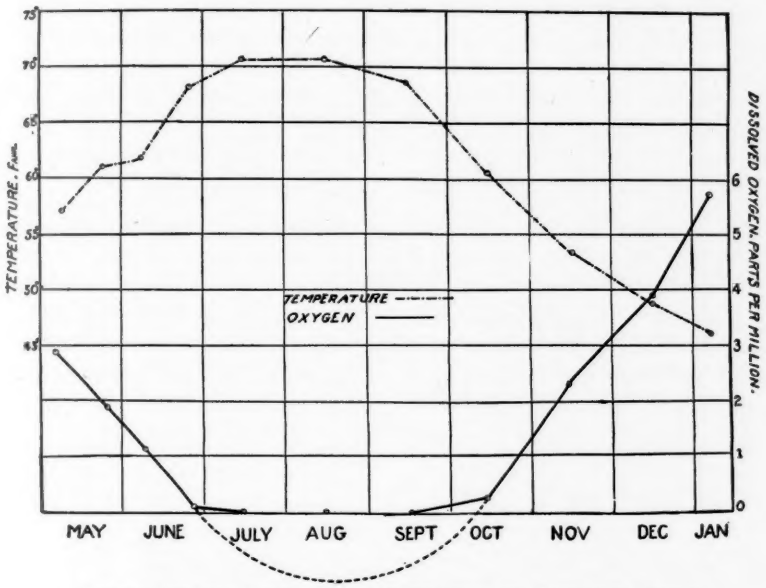
lected at the Sewage Experiment Station, a place at which the majority of the sewage arrives when less than an hour old, the amount of the dissolved oxygen is a seasonal function. It is entirely absent during the three summer months, begins to appear in the early fall, and reaches a maximum value sometime in midwinter, decreasing again as the warmer weather arrives.

In Table II are given these results, together with the temperatures for nine months. The figures given are monthly or semimonthly averages of almost daily determinations. During May and June the changes were so rapid that semimonthly periods were chosen instead of the monthly periods used during the remainder of the year.

TABLE II

Month.	Average temperature, F.	Average amount of dissolved oxygen. Parts per million.
May 1 to 16	57	2.9
May 17 to 31	61	1.9
June 1 to 15	62	1.1
June 16 to 30 . . .	68	0.1
July	71	0.0
August	71	0.0
September	68	0.0
October	61	0.3
November	53	2.2
December	49	3.9
January 1 to 15 . . .	46	5.7

In the accompanying diagram these figures are given in graphical form. From the manner in which the oxygen line approaches the axis, the dotted portion of the line, lying below the axis, is suggested. This would, of course, mean a negative value for the dissolved oxygen. In reality we may have some such a condition as this, although it is not truly a negative dissolved oxygen. After the dissolved oxygen of the sewage is entirely used up, the microörganisms begin to draw upon other substances containing oxygen. Sulphates, phosphates, and ferric



CURVES SHOWING RELATION OF TEMPERATURE TO DISSOLVED OXYGEN IN BOSTON SEWAGE

salts are reduced, giving rise to products which will readily become oxidized again upon exposure to oxygen. If such an extremely anaërobic sewage be mixed with equal portions of water containing, let us say, ten parts per million of dissolved oxygen, and the dissolved oxygen of the mixture determined immediately, the amount found will be small or altogether wanting. It is this ultra-anaërobic condition of a sewage which I have represented by the dotted line, although its existence in this case is purely hypothetical. Its determination by the method indicated is entirely feasible, and the actual condition of a sewage containing no dissolved oxygen can only be expressed in terms of this negative quantity which I would call "*oxygen avidity*."

The order of disappearance of the three forms of oxygen, namely, the free dissolved oxygen and that of the nitrates and the nitrites, seems to vary with the other variable conditions. Nitrates are found in the fresh Boston sewage most commonly in midwinter, and the nitrites generally have their maximum at that time, but there is no such direct seasonal effect noticeable as there is with the free oxygen. In some

laboratory experiments made to determine, if possible, the order of disappearance of the three forms, the effect of temperature and of the organisms present was strikingly shown. These experiments were carried out as follows: A sample of fresh sewage was collected directly from the manhole of the sewer. With this three bottles were filled. To each bottle was then added a small amount of paraffin oil to keep the sewage out of contact with the air. Dissolved oxygen samples were then taken from each bottle by means of a siphon. Samples were also taken for nitrates and nitrites. Bottle No. 1 was kept at a temperature of about 10° C., and bottles Nos. 2 and 3 at about 22° C. To bottle No. 3 a small amount of sludge from a septic tank was added in order to seed it with the septic tank organisms. The changes in the amount of dissolved oxygen, nitrates, and nitrites were then studied by determining these substances at intervals. The results of the series are shown in Table III.

TABLE IIİ

Time.	Parts per Million of Oxygen as		
	Free, dissolved.	Nitrates.	Nitrites.
Experiment I. Raw Sewage. Temperature, 10°			
1/13–10 A.M.	5.8	2.7	3.8
1/13–2 P.M.	5.0	3.0	3.8
1/13–5 P.M.	1.0	10.7	0.8
1/14–10 A.M.	0.0	0.0	0.0
Experiment II. Raw Sewage. Temperature, 22°			
1/13–10 A.M.	5.7	2.7	3.8
1/13–2 P.M.	2.0	0.0	0.0
1/13–5 P.M.	0.5	0.0	0.0
Experiment III. Raw Sewage Seeded with Septic. Temperature, 22°			
1/13–10 A.M.	5.5	2.5	3.4
1/13–12 M.	0.0	0.0	1.7
1/13–2 P.M.	0.0	0.0	0.0

Apparently under various conditions of temperature the relative changes in these three substances may be in one or another direction, and these changes are influenced by the bacteria. While it is perfectly feasible to define the several conditions of a sewage in terms of these three oxygen factors, and, if necessary, to determine, as in the experiments cited, the direction of the changes taking place, yet we are not able, with our present knowledge, to apply these condition factors to the practical problems of sewage treatment. That there is a considerable seasonal difference in the results of sewage purification is well known. In ordinary out-of-door work this difference is in favor of the summer season for reasons which are manifest. By eliminating as far as possible the effect of temperature upon the filter itself, which is possible only with small, indoor filters, these seasonal differences are reversed, the fresher winter sewage, with its plentiful supply of oxygen, being much more readily purified. This general observation is about all that we can make at this time. How much of this effect is due to the mere presence of the oxygen in preserving the activity of the filter, how much to the preponderance of bacterial nitrification over bacterial reduction (as shown in Experiment I), and how much to the absence of putrefactive changes which are themselves induced largely by the lack of oxygen, are questions to be answered by future investigations, and they are questions which must be fairly met and answered before we may claim to have a thorough knowledge of the purification processes with which we are dealing.

One word may be said in favor of the practical use of the condition factors here suggested. Results obtained empirically on any one sewage will be made available for general use only after we have discovered what are the important characteristics of sewage in relation to its treatment. Concentration and, to a large extent, composition characteristics are directly comparable. If these condition factors are found to be essential ones in determining the results of sewage treatment, then we may reasonably hope in the near future to be able to make use of the large amount of empirical data which today has little value except in reference to the sewage on which it was obtained.

Chlorine

It would seem from wholly *à priori* reasoning that the relation of the chlorine to the total nitrogen in sewages from various localities would be a fairly constant quantity, these two elements being both of funda-

mental character in food. Such, indeed, is the case in the majority of instances, although an occasional striking exception seems to lessen the value of the ratio in fixing the composition of a sewage. Unfortunately the data available for determining this ratio with exactness are very meagre. Clark (1904) gives the results of total nitrogen determinations on the sewages of sixteen cities and towns of Massachusetts. Five or six determinations were made on each sewage; the albuminoid ammonia determinations were made at the same time. From this series of results the writer has calculated the average ratio between the albuminoid ammonia and the organic nitrogen for each locality. In another place in the same report are given yearly averages of monthly analyses of these same sewages, but without organic nitrogen determinations. Applying the ratio previously found to the albuminoid ammonia figures given in these averages, it has been possible to estimate with fair accuracy the amount of organic nitrogen, and from this to establish the desired chlorine-nitrogen ratio. Table IV contains the results obtained in this way. Some results obtained by Fuller (1894) from four of these localities and one other, as well as the results from three English cities obtained by Rideal (1904), are also given.

The sewages from these cities and towns show, with a few exceptions, a fairly constant chlorine-nitrogen ratio of from one to one and a half. Three of the sewages are strikingly peculiar — Concord, Lawrence, and Natick. In Concord a large amount of ground water finds its way into the sewers, as is indicated by the extreme dilution of the nitrogenous material. There can be little doubt that a large part of this water is purified sewage with a high chlorine value. In Lawrence the very abnormal chlorine value may be due to mill liquor. Both Natick and Leicester have dilute sewages whose high chlorine ratios may be due to chlorine in the diluting ground water. The fact that a fairly constant ratio can be obtained in the case of most localities makes it seem very probable that the exceptions represent real variations from the normal domestic type.

TABLE IV.—SHOWING THE RATIO OF THE CHLORINE TO THE TOTAL NITROGEN IN SEWAGES FROM VARIOUS SOURCES

(Parts per million)

Place.	Nitrogen as			Chlorine.	Cl ÷ N
	Free ammonia.	Total organic (calc.).	Total.		
Andover	39.7	16.8	56.5	70.0	1.2
Clinton	33.3	23.7	57.0	59.5	1.0
Concord	5.7	4.2	9.9	26.6	2.7
Framingham	26.1	16.3	42.4	69.9	1.6
Gardner (old)	20.2	14.8	35.0	33.8	1.0
Gardner (new)	27.3	19.8	47.1	43.8	0.9
Hopedale	18.3	8.5	26.8	22.3	0.8
Lawrence	18.1	23.4	41.5	120.1	2.9
Leicester	22.0	8.3	30.3	54.7	1.8
Marlborough	25.9	14.8	40.7	59.0	1.4
Natick	12.2	7.9	20.1	59.5	2.9
Pittsfield	12.0	20.4	32.4	25.7	0.8
Southbridge	16.1	8.9	25.0	29.0	1.2
Spencer	14.9	11.4	26.3	39.9	1.5
Stockbridge	9.8	3.3	13.1	12.8	1.0
Westborough	13.8	11.1	24.9	23.7	1.0
Framingham	22.0	14.9	36.9	27.0	0.7
Gardner	8.8	9.6	18.4	29.0	1.6
Lawrence	10.8	14.5	25.3	37.5	1.5
Marlborough	27.1	20.4	47.5	45.0	0.9
Worcester Hospital	6.1	32.0	38.1	32.5	0.9
Exeter, England	. .	. .	63.7	75.0	1.2
Sutton, England	. .	. .	88.1	89.9	1.0
London, England	. .	. .	70.6	104.0	1.5

Fats and Fatty Bodies

The determination of the fats and soaps in sewage is one whose importance is generally overlooked. These bodies are undoubtedly responsible for much of the clogging properties of a sewage which are noticed particularly in sand filtration. The fats, being non-miscible with water, are the less readily decomposed, a feature which is augmented by the very stable nature of the bodies themselves. Clark (1904) gives as the average yearly amount of these bodies, fats and soaps combined, in the Lawrence sewage about six parts per hundred thousand, or 20 per cent. of the total combustible solids. In the treatment of the sewage of large private country residences great difficulty is found in properly dealing with the fats, which in this case amount to a very much larger percentage of the total solids. In one such case which has recently come under the writer's study the sewage contained 2,100 parts per million of volatile solids, of which 1,400 parts per million, or 66 per cent., were fats. In our interpretation the fats have a value as concentration factors only. Their determination is of considerable importance for the sake of comparisons, and should be made regularly in any systematic study. An occasional determination of the separate substances, free fats, and soluble and insoluble soaps, would also add to our knowledge of the character of the sewage. This separation is easily made by the use of suitable solvents.

Iron, Sulphur, and Phosphorus

The determination of these elements is not, as a rule, made in routine work. It would be extremely useful, however, to establish the normal amounts of these elements present in domestic sewages from various localities. Such data would be of value in calculating the amount of added industrial waste or other liquor which contained these elements. During the past year the writer has collected during each week an average sample of Boston sewage composed of equal portions of each daily sample. On this sample the iron and sulphates have been determined. The sulphates in this case are influenced by the presence of sea water and are, therefore, of no significance here. The iron-nitrogen ratio is found to be 0.2 for the yearly average. Variations in this ratio are slight.

Turbidity, Sediment, and Solids. Loss on Ignition

The turbidity, if determined by a properly standardized method, is a rough measure of the suspended solid matter. The sediment is the amount of this matter which has settled out after a given period. The total solids are usually determined on the filtered as well as the unfiltered sample. The difference between these two determinations gives the amount of solid matter in suspension, that is, the turbidity. Probably the most accurate optical method of estimating turbidity is by some such instrument as the Jackson turbidimeter.[1] This instrument is calibrated against finely divided silica, and its readings on turbid waters are in close agreement with the actual gravimetric values found for the solids in suspension. It is unfortunately true that an optical instrument of this nature gives correct values only when the suspended matter to be determined is of the same size as that matter against which the instrument was calibrated. In reading sewage turbidities in terms of silica there is a greater and greater variation between the turbidities and the actual solids in suspension as the size of the suspended particles increases. Clark (1904, *a*) has recently proposed as a standard for sewage turbidities, and especially for the fairly coarse suspended matter in certain filter effluents, a suspension containing a known amount of this same coarse and at the same time fairly stable material. From this standards may be made up containing varying amounts of the suspended solids. By using such a material to recalibrate the Jackson turbidimeter, one should be able to read the solids in suspension in a sample of sewage with a very fair degree of accuracy. If the suspended solids are determined in this way there seems to be little need for the total solids determination. Its results are at best open to suspicion, owing to the difficulty of completely drying a sample without loss of organic matter. This is especially true in the presence of deliquescent salts.

The sediment may be determined by a second reading of the turbidity after the sample has stood for a standard length of time.

The loss on ignition shows in a rough way the amount of the total solids which are volatile at a low red heat. It therefore includes the organic matter, with the exception of some of the carbon which may remain behind as alkaline carbonate. It also includes all such volatile

[1] Technology Quarterly, 1901, XIV, pp. 285–294.

substances as ammonium carbonate and chloride, and to a slight extent other mineral salts. The determination has never been regarded as one of much value.

Alkalinity

Domestic sewage is normally slightly alkaline. The alkalinity of a sewage has little significance in the interpretation unless it has an abnormal value. Such a characteristic might indicate the presence of industrial wastes which would otherwise have escaped notice.

Bacteria

The determination of the number of bacteria present in the sewage gives us in general little if any additional knowledge as to its characteristics. In certain special cases their total absence or presence in comparatively small numbers might direct the attention of the analyst to the presence of germicidal bodies in the sewage which would have otherwise escaped detection. In the discussion of the question of effluents the determination of the number and kinds of bacteria will be shown to have considerable significance.

Unfiltered and Filtered Samples

It is the usual custom in this country to make the principal determinations both upon the unfiltered sample and upon a sample which has been passed through filter paper. The differences noted are assumed to represent the amount of the substance in question which has been removed by filtration, and hence roughly the amount in suspension. In the determination of the total nitrogen or total carbon, such an assumption is legitimate. In using such comparative processes as the albuminoid ammonia and the oxygen-consumed processes, however, an error of considerable magnitude is thereby introduced. For example, the writer found in an extended comparison of the albuminoid ammonia with the organic nitrogen that as an average of a number of determinations 40 per cent. of the dissolved nitrogen and only 25 per cent. of the suspended nitrogen were recovered as albuminoid ammonia. In such a case the albuminoid ammonia might show equal amounts of nitrogen dissolved and suspended, when actually nearly two-thirds of the total would be in suspension.

In Germany and among certain English analysts samples are always filtered through paper before analysis. Such analyses are then published as analyses of the sewage. In defense of this practice it is said that an analysis of the sewage itself and not of the suspended solids is what is desired. Further comment is unnecessary except to state that such analyses are in no way comparable with our own.

Conclusion

In conclusion it may be well to bring together the various important analytical figures and factors which have been discussed in the preceding pages.

For concentration factors we should have determinations of the total nitrogen, total carbon, chlorine, and fats and soaps. Of minor importance, but useful in a systematic study for comparison, are the determinations of the sulphates, phosphates, and iron.

For composition factors the ratio of chlorine to nitrogen is perhaps under the present conditions of our analytical methods the best that we have. With the determination of the total carbon, the carbon-nitrogen ratio ought to prove of even greater value. The ratio of oxygen consumed to total nitrogen is only rough at best and is not independent of condition. It will, however, indicate any considerable change in the character of a given sewage, such a change as would be caused, for example, by a heavy summer shower.

For condition factors we have at present two independent sets of numbers. The oxygen values as found in the dissolved oxygen, nitrates, and nitrites serve as an admirable index of the condition of a sewage before putrefaction becomes active. During the later stages the free ammonia-organic nitrogen ratio is of great significance. The ratio of carbon oxidized by permanganate to total carbon may be found to have some value in determining condition. As a first prerequisite, however, a method must be developed for the oxygen consumed determination which can lay some claim to accuracy and constancy. In the accompanying sewage analysis there are given in ordinary type the analytical data which the writer believes will be found essential to a satisfactory interpretation of the analysis. The determinations in italics are not regarded as essential, but are of value in a systematic study of various sewages. New determinations will undoubtedly be added, such as, for instance, one which will show the tendency of the nitrogenous matter

to hydrolyze (putrefy); possibly some new ratios will be found to denote condition, but in the main the analysis here given is an example of what ought to be done in sewage analysis. No argument based upon the time consumed in making such an analysis should have weight against the adoption of this procedure. The tendency should be towards average samples taken from the whole day's run of sewage or the whole discharge of an effluent. A thorough knowledge of the action of various germicidal bodies in preserving such samples is desirable. Certain determinations will doubtless have to be made immediately, but the majority of the determinations here recommended can be made on an average sample of one whole week if necessary. Fewer but more representative samples examined thoroughly will take no more time than the rough analysis of many samples.

The writer would emphasize the statement already made that the object of these proposed factors is not to enable the analyst to say that any given sewage is of a certain age or of a certain composition. Such information might be more readily and accurately gathered from a survey of the sewerage system, and in fact no such concrete reference can be made from the analysis. It is known, however, that a study of our filtration results, and especially those obtained at our experimental plants, leads us at present only to empirical data which are correlated but slightly with one another or with the results from other plants. It seems more than probable that such a condition is due to lack of proper interpretation of our analyses, and that if we can truly interpret these analyses in terms of essential characteristics from the point of view of purification, and study our purification results on the basis of this interpretation, then we shall find that these results are correlated with the analyses and with one another, and that it may be more possible than heretofore to predict the probable effect of treating a given sewage by a given system of purification.

In the present paper we have considered only the subject of raw or untreated sewages and of septic sewages. The analysis of the effluent of a sewage filter is made for the distinct purpose of estimating the efficiency of the process of purification, and the interpretation of such an analysis requires a treatment quite distinct from that given here to sewage analyses. In a future paper the writer hopes to take up the discussion of this other important phase of the interpretation of sewage analysis.

TABLE V. — SPECIMEN SEWAGE ANALYSIS

	Parts per Million.		
	Total.	Dissolved.	Suspended.
NITROGEN:			
Total	55.6	40.6	15.0
Organic	30.0	15.0	15.0
As NH_3	25.0	. .	. .
As N_2O_3	0.1	. .	. .
As N_2O_5	0.5	. .	. .
CARBON:			
Total	280.0	120.0	160.0
By $KMnO_4$	14.0	8.0	6.0
As CO_2	5.0	. .	. .
CHLORINE	60.0	. .	. .
OXYGEN:			
Dissolved	10.0	. .	. .
FATTY ACIDS:			
Total	61.0	30.0	31.0
Saponified	35.0	30.0	5.0
Unsaponified	26.0	. .	26.0
Sulphur	7.0	. .	. .
Phosphorus	1.0	. .	. .
Iron	12.0	. .	. .
Alkalinity	212.0	. .	. .
TURBIDITY:			
Total	320.0	. .	. .
On standing	260.0	. .	. .
Sediment (diff.)	60.0	. .	. .

RATIOS:

Carbon-nitrogen	5.1
Chlorine-nitrogen	1.1
Ammoniacal-organic nitrogen	0.83
Carbon by $KMnO_4$-total carbon	0.05

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ON A SCALE OF COLOR-VALUES AND A NEW PHOTOMETER[1]

By ALBERT H. MUNSELL

(Read October 27, 1904)

The definition of color involves three qualities: hue, value, and chroma; or, in terms of the wave theory, wave length, wave amplitude, and wave complexity. The second of these qualities is paramount in picturesque art, for, although the painter may employ considerable latitude as to hue, small errors of value quite distort the shape of familiar objects.

Thus in a portrait, if the rosy hue of the cheek be made too light or too dark for the surrounding color, that surface seems in advance of the head or is plunged back of the malar bone. In landscape art, failure to relate these values properly makes it impossible to render the illusion of outdoor nature.

Helmholtz says that he finds it very difficult to compare the luminosity of different colors; but every worker in color is constantly called upon to make such comparisons, and the half dozen years of academic study required to train an artist are largely spent in experiments with color-value. It is true that the results are likely to fluctuate with the mental and physical state of the painter, but in spite of this personal bias a tolerable consistency of relation is indispensable to his success.

Unlike the musician, who is trained to the correct estimate of musical values by a system of measured intervals, the painter has no system and can refer to no established scale of color-value. Not many centuries back musical intervals were unmeasured, and a friend of Pope Gregory remarked that "unless sounds be retained in the memory they must perish, for they cannot be written." Today that seems to be the situation in color. There is no established standard of color intervals, while the terms employed to describe color are too meagre and loose to define its subtle differences. Perhaps this accounts, in part, for the tendency to borrow musical terms, such as tone, pitch, key, chord, and symphony.

[1] Patented November 19, 1901.

Believing a measured scale of color would be valuable both for reference and in the training of the eye, experiments were begun some years ago with a tentative scale of gray values evenly spaced from white to black. This was criticised by artists, dyers, salesmen of colored goods, and others, who were asked to select the middle value, *i. e.*, a gray midway between the extremes of the scale. To test further this choice, the selected gray was placed between white and black, so that a slight shift of value could be made if desired, until the eye accepted the two intervals as of equal contrast.

This average choice of middle value then served to grade a scale of ten steps made by the use of Maxwell disks. Finding, however, that for equal steps of sensation, the increase of white above middle gray was more rapid than it was below that point, the areas were readjusted to conform to a geometric curve (Weber's law[1]). When this scale was submitted to Captain Abney, he replied, "I should say that your scale is one to be trusted."

Finer subdivision was obtained by marking the circumference of a white circular disk in 100 steps to agree with the geometric curve, and combining it with a disk of black velvet. Both disks had a radial slit so that any desired areas of the two could be united. A motor was arranged to drive two shafts, one of which carried the variable disks, while on the other was placed a sample of gray or of any color whose value it was desired to ascertain. In rapid rotation the black and white disks of variable area appeared to melt into a uniform gray, and by varying the proportions until this gray matched the luminosity of the sample its value could be read from the circular scale as a percentage of white.

But this method had the disadvantage of being slow, and there was risk of lateral reflections from the walls and objects in the studio. The eye also became fatigued by the flashing of the black and white disks as they gained speed. In casting about for other means, comparisons were made on a Bunsen photometer, only to realize fresh difficulties, both from the color of the light and from the fact that its best efficiency is limited to values between 35 and 65 per cent., above and below which the ratios are not reliable.

Since the problem was distinctly photometric, yet apparently not solved by existing forms of the instrument, the natural desire was to devise a new one for this purpose. Experiments were made with

[1] Wundt: Grundzüge der physiologische Psychologie. Ed. 5. I, 1902, p. 497.

devices ranging in size from a jewel box to a chest. They were pierced with openings of various shapes for shutters and observation tubes, fitted with diaphragms at various angles to temper the light, while screens and mirrors were used to lead the light to the eye. A model was at last perfected which served either with natural or with artificial light, and was so compact as to be easily portable.

The essential idea was that if a white card be properly safeguarded from stray light, and its illumination controlled by a suitable shutter, it may be made to trace the complete scale from white to black. Certain intervals of this scale are given by the diaphragms used in a photographic camera, and an instantaneous shutter traces the entire scale at a flash. If instead of this shutter we substitute one which will stand at any desired degree of opening, and then place a white card in the plate holder, the camera furnishes an easily measured scale of value, without the disadvantages already noted in the use of Maxwell disks.

The next question is to adjust the sample beside this variable scale. The illumination of the sample must remain constant while that of the white card is varied, and the eye must be able to observe both throughout the process. This is accomplished by placing the sample in a second camera, identical in every way except that it is not fitted with a shutter, and combining the two side by side with the thinnest possible septum. An eyepiece then permits observation of the interior of both cameras, without allowing any stray light to enter, and one watches the alternate darkening and lightening of the white card by the adjustable shutter until the value of the sample is matched.

The shutter, or adjustable valve, is known as a cat's-eye. Its aperture is always square and central at every degree of opening, making it easy to measure the volume of light admitted to the camera in terms of the side or the diagonal.

Although the manipulation of such an instrument is simple enough to be understood by a child, the problems that arose during its development were by no means simple. In trying to follow the law of sensation as exemplified by the scale first described, nearly a score of shutters were made and calibrated, and the cat's-eye finally was adopted because of its easy verification. There were numerous optical questions as to the use of lenses and mirrors, as to the proportions which would give the best effective illumination, the diffusers necessary to prevent the effect of pin-hole photography as the shutter closed, and in general the best conditions for visual ease in making the comparisons.

Amid these difficulties helpful suggestions were given by Professor Cross and Professor Clifford of the Institute and by Dr. Bowditch of the Harvard Medical School, in whose laboratories the first instruments were installed. They are of portable size, weighing 10 pounds, and

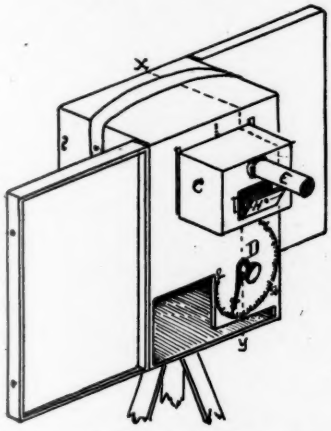

FIG. 1. — THE MUNSELL PHOTOMETER OPEN AND READY FOR USE

C, cabinet; *D*, dial; *E*, eyepiece; *H*, holder; *x y*, plane of Figure 4

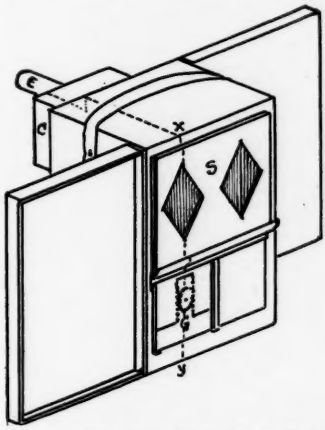

FIG. 2. — OPPOSITE SIDE OF THE SAME

G, gear for shutter; *S*, screen; other lettering as in Figure 1

measuring 8 x 11 x 14 inches. Details of their mechanism are shown in Figures 1 to 5.

Figure 1 shows the instrument open and mounted ready for use upon a tripod. *D* is a dial divided into 100 parts. The dial hand is carried on a shaft whose gear actuates the shutter, so that when it stands at 0 all light is excluded from the variable half, and with the hand at 100 full light is admitted. *E* is an eyepiece inserted into the cabinet, *C*, which contains a mirror reflecting both the scale and the sample. *H* is a hinged door, or holder, carrying both the sample and the standard white whose obscuration by the shutter furnishes the complete scale of value. When not in use, the cabinet and eyepiece are dismounted and stored in the open space to the left

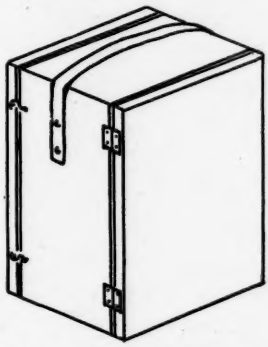

FIG. 3. — THE PHOTOMETER CLOSED

of the dial, permitting the instrument to be completely closed, as in Figure 3.

Figure 2 is a view opposite to that in Figure 1, showing the two similar openings which illuminate the variable and the fixed half of the instrument. *S* is a diffusing screen to distribute the light evenly and prevent the effect of pin-hole photography as the shutter closes. Behind this screen plays the cat's-eye shutter, consisting of two leaves superposed, and pierced with square openings that exactly register when the shutter is open. These leaves move in opposite directions when driven by the gear, *G*, preserving a central opening which is always square until absolutely shut, and thus allows easy verification of the dial in terms of the volume of light admitted by the square opening.

Figure 3 is the instrument closed for transportation.

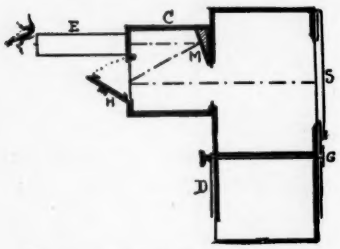

FIG. 4.—VERTICAL SECTION IN THE PLANE *x y* OF FIGURES 1 AND 2

C, cabinet; *D*, dial; *E*, eyepiece; *G*, shutter-gear; *H*, holder; *M*, mirror; *S*, screen

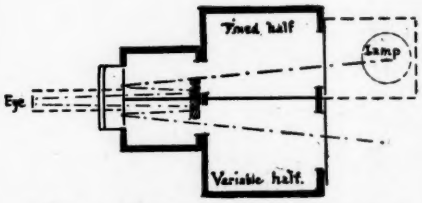

FIG. 5.—HORIZONTAL SECTION THROUGH THE OPENINGS

Figure 4 is a vertical section through the centre of the variable half, as shown by the line *x y* in Figures 1 and 2. Light enters through the diffusing screen, and is controlled by the variable shutter so as to produce any desired illumination upon the standard white. This is reflected to the eye by the mirror, *M*, and viewed through the eyepiece, *E*. A shaft connects the dial hand with the gear actuating the two leaves of the shutter, whose symmetrical balance obviates any tendency of the opening to alter when a reading is to be made.

Figure 5 is a horizontal section through the centre of both openings admitting light to the symmetrical halves of the instrument. Smaller openings in the face of the cabinet permit the light to reach the standard and sample in the holder, and also act as diaphragms to further ensure the equalization of light in both halves. Two beams of identical character, emanating from the same source, yet entirely isolated, are

thus allowed to fall on the holder at the back of the cabinet. The eye is enabled to see and compare the relative luminosity of standard and sample by means of the mirror, and when both are equally luminous the dial hand indicates the value of the sample in terms of standard white.

The description thus far has assumed a single source of illumination — either daylight, as at the north window of a studio, or an artificial light. But provision is also made for comparing the light from different sources and its effect upon different colors, as when the change is made from natural to artificial illumination. This is indicated in Figure 5 by the dotted line in front of the fixed opening, which represents a closed box containing an incandescent lamp, or any other convenient form of artificial source. This box can be adjusted to either half of the instrument, and the source of light contained may then be taken as a basis of comparison for other degrees of illumination.

Calibration of the Instrument[1]

The dial of the photometer (Figure 6) is provided with two scales, an outer and an inner one. The outer scale is divided into 100 equal degrees of value, *i. e.*, sensation of luminosity, from 0 = complete blackness to 100 = pure white illuminated to the full extent of the instrument, 50 being the middle value. It differs thus from the usual photometer scale in being a scale of *sensation* instead of *intensity* of light. But the instrument is so constructed that the pointer moving over this scale gives also an accurate measure of the diagonal of the variable aperture in millimeters. As the area of the aperture, and hence the amount of light admitted, is proportional to the square of the diagonal, it is

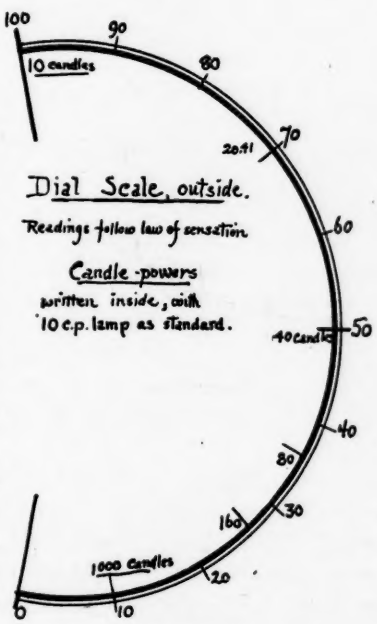

Fig. 6. — Photometer Scale

[1] This section has been recast by the Editor.

easy to calculate the relative intensity of illumination from the reading on the scale of values.

The relation between the intensity of light and the sensation of value is found to be as the ratio of a number to its square root, and this is illustrated by the curve (Figure 7). It will be seen that we

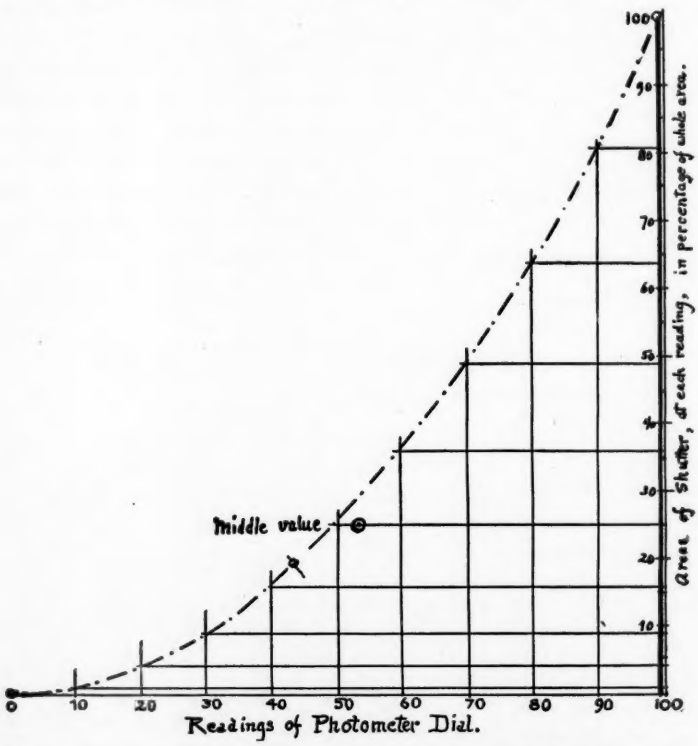

FIG. 7.—CURVE SHOWING THE RELATION BETWEEN READINGS OF THE SCALE OF VALUES ON THE DIAL AND AREAS OF THE SHUTTER ADMITTING LIGHT

have here Weber's law of the relation between stimulus and sensation expressed by a curve of square roots instead of the logarithmic curve of Fechner.[1] Thus, if our scale of value runs from 0 to 100, the corresponding scale of light will extend from 0 to 10,000, and 50 per cent. of value, middle gray, will correspond to 2,500, or 25 per cent.,

[1] Wundt, *loc. cit.*

on the scale of light. Or, if $V =$ value, $L =$ light, and K is a constant dependent upon the scales of light and value used, then $V = K\sqrt{L}$.

The inner scale is intended to be used for testing sources of light, a 10 candle-power lamp being taken as the standard. For sources of light more intense than the standard this is arranged to be used in the opposite direction to the scale of values. Thus to balance the standard with a lamp twice as intense the shutter must be choked down to half the full area; for a lamp four times as intense it must be reduced to one quarter the full area. Hence forty candles on the inner scale corresponds to 50° on the outer one. For when the shutter is adjusted to balance a stronger light against the standard, the candle-power indicated will be the reciprocal of the fraction of the full area multiplied by the standard. That is, if a lamp having C candle-power appears of equal value to the standard of C_s candle-power when the area of the shutter is reduced to $\frac{1}{m}$ of the full area, A, then $C = mC_s$, and $K\sqrt{\frac{1}{m}A}$ will give the corresponding reading on the scale of values.

Brief Directions for the Use of the Photometer

Test. — Place the instrument on a tripod or table, about 3 feet from the source of light. Centre by means of the screw heads at the top, so that both halves of the white field on the holder are equally illuminated. Avoid lateral reflection from any surface. With the shutter fully open (100 on dial), the white appears identical on both sides of the central partition. With closed shutter (0 on dial), one-half is rendered absolutely black.

Sensitive readings can be had at a north window receiving unbroken sky illumination for three hours either side of the meridian, or at night from a 16 candle-power lamp, 3 feet distant and screened by a square foot of ground glass.

Method 1: To Determine the Value of Reflected Color. — The degree of light reflected from a sample of colored goods is found by placing the color sample on the fixed half of the field, adjoining standard white on the variable half. The cat's-eye serves to increase or diminish the light on the standard white, until both halves appear equally luminous; the value of the color then may be read on the dial.

This is its *daylight* value. By substituting artificial light, the dial will register the gain or loss of luminosity which this color exhibits in a changed illumination.

Inversely, the color of any light may be plotted as a curve, significant of its effect upon a series of colored samples. No dark room is needed for these comparisons, as a blackened box containing the artificial light is readily fitted to the front apertures, and the eye of the observer remains immersed in daylight. This method applies to all pigments and colored materials, such as silks, woolens, cottons, papers, enamels, etc., which *reflect* light.

Method 2: To Determine the Values of Transmitted Color. — A sample of colored medium, as, for instance, a red signal glass, is secured over the fixed opening, and that half of the field appears red by its transmitted light. The variable half of the field is then alternately darkened and lightened by smaller intervals, until both halves appear equally luminous, when the dial registers the percentage of light perceived through the red glass. Various red glasses reduce the apparent luminosity from 63 to 87 per cent. of the outer scale.

When a signal glass has been standardized, the illuminating power of various signal oils is readily measured by use of the inner scale on the dial.

Method 3: To Determine the Illuminating Power of Light Sources. — The candle-power of an electric lamp is readily ascertained. The dark box, which can be adjusted to either of the front openings, is fitted with a standard lamp (reflector pattern preferable) and connected with a storage battery of known voltage. The lamp to be measured is placed symmetrically with the standard lamp in its dark box, with the lamp of supposedly greater power, illuminating the variable half of the field.

The field is then equalized as before by the shutter, and the *inner scale* of the dial registers candle-power directly. This can be done even though the *sources of light are of different color,* which is difficult with the Bunsen and other photometers. When the lamp to be tested is of less candle-power than the standard, it is only necessary to reverse the position of the standard and calculate the ratio.

If the lamps compared do not greatly differ in intensity, a darker field inserted on the fixed side, brings the readings below 30 of the dial, where the eye is very sensitive to small differences of illumination.

This offers a direct test of the efficient illumination, which often

does not accord with the candle-power rating of lamps, for while the current may remain constant, the lamps steadily deteriorate by darkening of the glass, waste of the filament, etc.

Method 4: To Measure the Diffused Light of a Room. — The relative illumination of any room, or the amount of light available at any point in the room, as at a desk or show case, is readily found by the above method when the standard lamp is connected by a flexible cord of convenient length. This permits of a series of readings at fixed intervals, from which a plot of the general illumination of the room is made as easily as the relative temperatures are obtained with a standard thermometer.

Method 5: To Test the Relative Sensitiveness of Each Eye to Light and Color. — The optician and the psychologist have in this instrument a ready means of testing individual retinal sensitiveness. The objective determinations above described serve as data in subjective tests. The dial may be screened so that the readings are unknown to the person who thus unconsciously records the sensitiveness of each retina to known lights and colors. It is of interest to note that persons who are color blind find such comparisons more easy than those who are sensitive to color, because with them the element of difference of hue felt by the normal person is not added to that of difference in value.

Personal Bias. — To trace the effect of the personal equation in photometric estimates, a table is given of readings from the same gray sample made by four individuals. The source of light was a 16 candle-power lamp screened by ground glass at a distance of 3 feet.

A is a set of readings by a painter who ordinarily wears glasses to correct inequality of the two eyes, but who discarded his glasses in these comparisons. A pretty constant interval between readings by the right and left eye can be traced.

J is a younger person who does not wear glasses, and the readings show that both eyes preserve an average of stimulation.

E is a six-year-old boy, and *G* is his nurse, totally unfamiliar with the instrument and the process, who showed some nervous excitement in the effort to read.

The total average of the readings by *A* is 50.25, by *J* it is 50.02, by *E* it is 52.5, and by *G* it is 52. The average reading of the four persons is 51.19, from which there is a departure of 1 per cent. in either direction.

When the above averages are plotted (Figure 8), it appears that the second reading in each is exaggerated, due perhaps to some action of the retina, when the observation tube shuts off all side illumination from the eye. As the eye becomes familiar with the conditions there is a downward trend in the readings, as if less stimulation were needed for the comparisons.

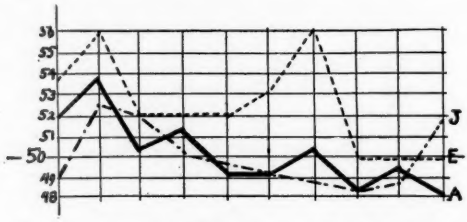

FIG. 8. — SERIES OF READINGS BY THREE PERSONS FROM THE SAME GRAY SAMPLE

A, ———, average 50.7; *E*, – – – –, average 52.5;
J, — — — — —, average 50.025

A.			J.			E.	G.
Left eye.	Right eye.	Average.	Left eye.	Right eye.	Average.	Right eye.	Right eye.
52.5	51.5	52.0	47	51.0	49.0	54	50
53.0	54.0	53.5	50	55.0	52.5	56	54
52.5	48.0	50.25	52	52.0	52.0	52	54
54.0	48.5	51.25	47	53.0	50.0	52	51
52.5	47.0	49.75	50	49.5	49.75	52	51
52.0	46.5	49.25	50	48.5	49.25	53	. .
52.5	48.0	50.25	49	48.5	48.75	56	. .
51.5	46.0	48.75	50	47.0	48.5	50	. .
53.5	45.5	49.5	47	50.5	48.75	50	
50.0	46.0	48.0	49	54.5	51.75	50	. .
52.4	48.1	50.25 Average of both eyes	49.1	50.95	50.025 Average of both eyes	52.5	52

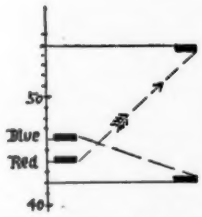

FIG. 9.—DIAGRAM SHOWING THE CHANGE IN RELATIVE LUMINOSITY OF TWO SAMPLES WITH CHANGE IN COLOR OF SOURCE OF LIGHT

Disturbance of Color Relations by a Change in the Color of the Source. — Figure 9 describes the effect of a change of light upon two different hues, the samples used being cut from ordinary red and blue tags. In daylight they appear of nearly the same luminosity (red, 44; blue, 46); but by substituting an incandescent lamp before the photometer, the blue loses 4 per cent., while the red gains 11 per cent. This inverts their position in the scale, and separates them by a total of 13 per cent. in value. This test was made by several persons, and one was discovered whose readings preserved the interval, but all the readings were moved five points higher in the scale, as if that increase of stimulation was needed by this individual to match the colors.

Figure 10 shows a similar test of two signal glasses, a red and a green. By daylight the green glass gives 60 per cent. of the apparent luminosity of the incident light, while over an electric lamp it is reduced to 34 per cent. The red glass by the electric illumination gives 24 per cent., but only 12 per cent. by daylight, so that the luminous values of these two signals which differ by 48 per cent. of the scale in daylight are separated by but 10 per cent. under the artificial light.

FIG. 10. — DIAGRAM OF THE RELATIVE VALUES OF TWO KINDS OF LIGHT TRANSMITTED BY TWO SIGNAL GLASSES

Disturbance of Color-values as a Result of Very Low Illumination. — The so-called Purkinje effects which colors suffer in a twilight illumination can readily be studied and measured by using a variable source of light, or by cutting down the volume admitted to the instrument.

Sources of Error and Precautions. — The first essential for accurate results by this method is absolute symmetry in the instrument. Any unevenness of material in the diffusing screen, or difference in the apertures which admit the light, must of necessity destroy the balance.

Should the halves of the mirror get out of plane, or if dust settles unevenly upon them, or should

a leak of light be caused by rough handling, it can be detected by placing a piece of standard white on both sides of the holder, when they will fail to balance. The test is made more complete by then reversing their places to see if the inequality persists. Failure to duplicate the readings shows inequality of the two halves, due either to one of the causes already named or to a failure to place the source of light centrally.

When used in daylight near a window care must be taken that surrounding buildings do not affect the color of the light, and if their sky line is very broken it is well to use only the overhead light of the sky by means of a mirror or a sheet of white blotter inclined at about 40° and a foot in front of the apertures. In a dark room or at night the centering of the source is easily verified by the screw sight on the top of the instrument.

Physicists who are familiar with this photometer find it sensitive and satisfactory in measurements of light and color, while its simple, portable character makes it very convenient for such comparisons. Special interest attaches to the fact that it forms part of a new system[1] for the identification of color by measured scales of hue, value, and chroma, which provides means for the plotting of color relations in quantitative terms and for their description by a definite notation.

[1] Munsell: A Color Notation. Boston, Ellis, 1905.

THE EFFECT OF SILVER ON THE CHLORINATION AND BROMINATION OF GOLD[1]

By H. O. HOFMAN and M. G. MAGNUSON

Introduction

When dry chlorine gas is made to act in the cold upon finely-divided gold,[2] it converts the latter with evolution of heat into auro-auric chloride, Au_2Cl_4, a hard, dark-red, hygroscopic salt. Moisture splits this salt into aurous and auric chloride, $Au_2Cl_4 = AuCl + AuCl_3$; treatment with water converts it into auric chloride and gold, $3\ Au_2Cl_4 = 4\ AuCl_3 + Au_2$. Aurous chloride, when stirred with water, undergoes a similar decomposition, $3\ AuCl = AuCl_3 + Au_2$. These decompositions of auro-auric chloride and of aurous chloride furnish the explanation for the practice of moistening an ore before it is treated by the Plattner chlorination process, practical experience having shown that gaseous chlorine gave an unsatisfactory extraction with dry ore.

According to Rose,[3] fine gold is acted upon more slowly by chlorine than gold containing some base metal, *e.g.*, copper. He also states that small quantities of silver increase the rate of solution, but adds that the coating of silver chloride formed checks, and finally stops, further action if the percentage of silver be increased beyond a certain undetermined amount.

Bromine[4] acts upon finely divided gold in a manner similar to chlorine; the auro-auric bromide, Au_2Br_4, however, is not hygroscopic. Upon treatment with water it is decomposed as is the corresponding chlorine salt. It is generally believed that bromine does not act as energetically upon gold as does chlorine. This seems to be borne out

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[1] Reprinted from Transactions of the American Institute of Mining Engineers, Lake Superior Meeting, September, 1904.

[2] Thomsen, Journal für Praktische Chemie, 1876, XIII, p. 337.

[3] Metallurgy of Gold, London, 1902, p. 268.

[4] Thomsen, *op. cit.*

by the results in the leaching plant of the Black Hills Milling and Smelting Company, Rapid City, South Dakota,[1] where barrel-chlorination and bromination were compared in the laboratory and in the mill, and chlorine was found to make poorer tailings than bromine. Rose,[2] however, in experimenting upon the rate of solution of gold by chlorine and bromine, found that bromine dissolved gold more rapidly than chlorine, and that the action of both was quicker at from 50° to 60° C. than at ordinary temperature.

Percy[3] describes two striking lecture-experiments which show how readily silver leaf is converted into silver chloride or bromide by the action of gaseous chlorine or chlorine water, or by bromine vapor or bromine water. A large bottle is filled loosely with silver leaf; upon introducing chlorine or bromine the leaf is entirely converted in a short time into white chloride or yellowish bromide. As to the effect of silver upon chlorination of gold, the only figures published are those of Dietzsch,[4] Wagemann,[5] and Coignet.[6] Dietzsch and Wagemann say that the gold must be at least 0.917 fine, if a satisfactory extraction is to be obtained, and Coignet asserts that gold with from 10 to 12 per cent. of silver is more readily dissolved than pure gold, but that gold with from 40 to 50 per cent. of silver cannot be treated by chlorine with a view of dissolving the gold.

In regard to the effect of silver on bromination of gold, no data appear to have been published.

In chlorinating gold with gaseous chlorine in a stationary vat, the gold should be more effectively protected by the silver chloride formed than when chlorine-water or bromine-water is used in a revolving barrel, as the coating of silver chloride or bromide formed will be removed more or less by the abrasive action of the charge upon the metallic particles.

The aim of the research to be described in this paper was to find the dissolving power of chlorine-water and of bromine-water upon gold and upon a series of alloys of gold and silver, the operations being carried out in revolving vessels.

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[1] Godshall, Engineering and Mining Journal, January 6, 1904.

[2] *Op. cit.*, pp. 267, 268.

[3] Metallurgy of Silver and Gold, London, 1880, Part I, pp. 56 and 110.

[4] Berg- und Hüttenmännische Zeitung, 1881, p. 13.

[5] *Ibid.*, 1889, p. 249.

[6] Bulletin de la Société de l'Industrie Minérale, 1898, XII, p. 762.

The Ore Charge

The ore used in the experiments was made up of quartzite and gold or gold-silver alloy. The quartzite was crushed to pass a 40-mesh sieve, and freed from particles of iron from the crushing machinery by means of a magnet and by boiling with acid. The alloys were prepared from chemically pure gold and silver. The metals were rolled into strips, the desired quantities then weighed out to 0.01 mg. and alloyed by fusing on charcoal before the blowpipe. The resulting globules were hammered to thin disks and each converted into a fine powder by holding in pinchers and rubbing the edge on a fine file, using a very slight pressure. Any particles appearing to be coarse under a magnifying glass were put aside. The quantities used were too small to allow the use of a limiting sieve; the size of particles is therefore not definitely given. A charge was made up of 5 assay-tons of 40-mesh quartzite and 10 mg. of metal, making thus an ore assaying 2 ounces per ton. The composition of the series of alloys tested was:—

	mg.	mg.	mg.	mg.	mg.
Gold	10	9	8	7	6
Silver	0	1	2	3	4

The Apparatus

The dissolving tests were made in pint fruit-jars of glass, 3 inches in diameter and 6 inches high, the covers being held in place by screw-

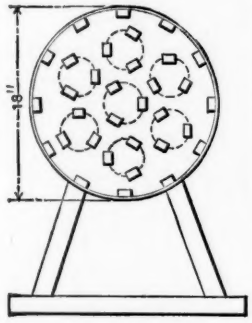

Fig. 1.—Richards Revolving Apparatus. End view

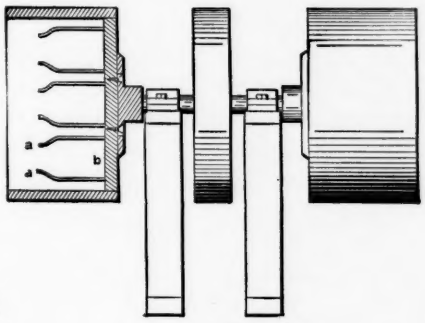

Fig. 2.—The Same
Side view

clamps, and the joints made tight by rubber gaskets. The jars were rotated in the Richards Revolving Apparatus, shown in Figures 1 and 2.[1] This is seen to consist of a horizontal shaft with pulley, having at either end a cylindrical box holding seven jars. Each box has a wooden bottom, twelve staves connected by a stout wire, and sides of 2.5-pound lead. A jar is held loosely in a horizontal position by three sheet-steel springs screwed to the wooden bottom. A circular felt pad, *b*, tacked down between three springs protects the bottle against jarring. The barrel makes 4.3 revolutions per minute.

The Solvents

In order to obtain a satisfactory extraction of gold by chlorination or bromination, it is essential to have an excess of reagent over that taken up by the ore. In working on a large scale, it has been found[2] that the consumption of chemicals per ton of ore is the larger the smaller the charge. Bringing this down to a laboratory scale, the quantities necessary will be much greater than those found in practice. Considering further the manner of preparing the finely-divided gold or gold-silver, which was coarser than that found in ores subjected to leaching, the excess of solvent in the present case has to be larger than that required by a natural ore in a laboratory test.

In comparing chlorine and bromine as solvents, it will be necessary to have equivalent quantities. Guided by experiences in regular laboratory practice,[3] the quantities of bromine settled upon, using 150 c.c. of water and 5 A. T. of ore, were 3.0, 2.0, 1.5, 1.0, 0.8, 0.7, and 0.5 c.c. According to Roozeboom,[4] a saturated solution of bromine in water contains at 0° C. 4.05 per cent. of bromine; at 3°, 3.8 per cent.; and at 10°, 3.33 per cent. The solubility decreases slowly with the temperature. Dancer[5] gives for 15° C. 3.226 per cent. of bromine, and for 30° 3.126 per cent. With 1 c.c. of bromine weighing 2.99 g., the equivalent of chlorine will be 1.32 g., according to the ratio, Br : Cl = 79.96 : 35.45 = 2.99 : x. The chlorine in the experiments was obtained by the action of sulphuric acid upon bleaching powder. The

[1] Ore Dressing, by R. H. Richards, II, p. 1157; reproduced by the courtesy of the Engineering and Mining Journal.

[2] Godshall, Engineering and Mining Journal, January 6, 1894, p. 6.

[3] Notes on Assaying, by R. W. Lodge. Wiley & Sons, New York, 1904, p. 248.

[4] Dictionary of Chemical Solubilities, by Comey. Macmillan & Co., London, 1896, p. 62.

[5] Comey, *op. cit.*

available chlorine in this was determined[1] by adding to a semi-solution of a weighed quantity of bleaching powder an excess of a standardized solution of arsenious oxide, titrating back with a standard solution of iodine, and calculating the available chlorine from the oxidized arsenious oxide. The bleaching powder contained 20.78 per cent. of available chlorine, or the weight of the desired amount of chlorine in grams has to be multiplied by 4.81 in order to obtain the necessary bleaching powder. Multiplying by five gives a slight excess. For each gram of bleaching powder used, 1.5 g. of concentrated sulphuric acid (specific gravity, 1.84) was added. The solubility of chlorine in water is limited. According to Gay-Lussac:[2] —

TABLE I. — Solubility of Chlorine in Water

1 c.c. = 1 g. water dissolves at ° C.*	c.c. Cl.†	gr. Cl.‡
0	1.43	0.0045
8	3.04	0.0096
10	3.00	0.0095
17	2.37	0.0075
100	0.15	0.0002

* Only part of temperatures given in the original are reproduced here.
† Not corrected to 0° C. and 760 mm.
‡ c.c. Cl × 0.00317344 = gr. Cl.

Mode of Operating

In making up a charge, the gold or alloy powder was well mixed with the 40-mesh quartzite and charged into the flask. In brominating, 150 c.c. of water was added, and then the required cubic centimeters of bromine dropped from a graduated pipette, keeping the tip under water. In chlorinating, the bleaching powder was mixed with the ore, the mixture filled into the flask, 150 c.c. of water added, and lastly the sulphuric acid. Although there is some danger of loss of chlorine in this method of charging, on account of the gas being sometimes evolved before the lid can be secured down firmly, it is to be preferred to charging the bleaching powder in bulk and then covering it with the ore, as the powder is not so liable to form lumps coated with calcium sulphate, which pre-

[1] Quantitative Chemical Analysis, by H. P. Talbot. Macmillan, New York, 1899 p. 111.
[2] Comey, Dictionary of Chemical Solubilities, p. 105.

vents further action of the sulphuric acid and thus gives less chlorine than called for by the test. The time of rotation was uniformly 5.5 hours, the barrel making 4.3 revolutions per minute. When the time had elapsed, the content of a jar was transferred to a 7-inch filter and washed for from two to three hours with from 800 to 1,000 c.c. of water, ferrous sulphate serving as reagent to test for gold; the residue

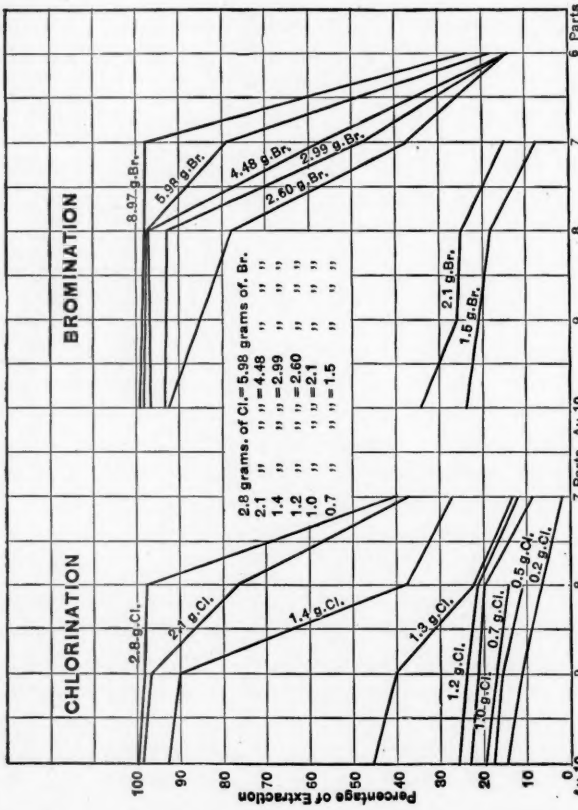

FIG. 3. — RESULTS OF CHLORINATION AND BROMINATION, SHOWING RELATION OF THE RATIOS OF GOLD AND SILVER TO PERCENTAGE OF EXTRACTION WITH GIVEN AMOUNTS OF REAGENT

and filter were placed on a roasting dish at the mouth of a muffle, dried, the filter burned, the whole passed through a sieve to break up all lumps and charged with the necessary fluxes into a Battersea crucible, mark K, and fused. The charge — comprising ore, 5 A. T.; sodium bicarbonate, 150 g.; litharge, 300 g.; argols, 10 g.; and the salt cover — gave in 1.5 hours a lead button weighing about 125 g., which had to

be reduced by scorification to about 25 g. before the cupellation. This was done in a 3.5-inch scorifier, necessitating one pouring-off of slag. The alloy buttons were parted in the usual way after adding the re-

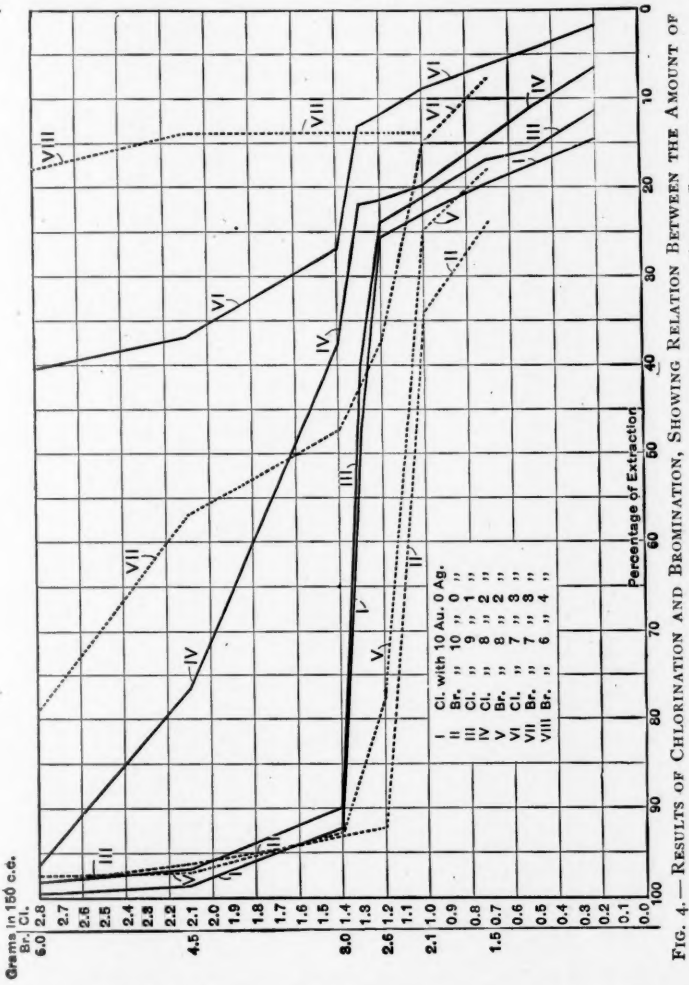

FIG. 4.—RESULTS OF CHLORINATION AND BROMINATION, SHOWING RELATION BETWEEN THE AMOUNT OF THE REAGENT AND THE PERCENTAGE OF EXTRACTION FOR ALLOYS OF GIVEN COMPOSITION

quired quantity of silver and fusing before the blowpipe. The conditions of assay were kept as uniform as possible, in order that any losses by slagging, volatilization, and cupel absorption might be the same, and the results correct in relation to one another.

Results

The results obtained are given in Table II for chlorination, and Table III for bromination, and graphically represented in Figures 3 and 4. The tables require no further explanation. In Figure 3 the constant is the quantity of active reagent, the variables are the percentage of extraction drawn as ordinate and the ratios of gold and silver drawn as abscissa. In Figure 4, which was plotted to bring out in a more striking way the dissolving effects of chlorine and bromine, the variables are quantity of reagent drawn as ordinate and the percentage of extraction drawn as abscissa, while the composition of the alloy is the constant. In analyzing the results of chlorination in Figure 3, it is seen that with pure gold the solutions containing 2.8, 2.1, and 1.4 g. of chlorine give good extractions, *i.e.*, 99.6, 98.6, and 92.5 per cent.; with 1.3 g. chlorine there is a sudden fall to 45.2 per cent., and with 1.2 g. a second decided lowering of extraction to 25.6 per cent.; from now on the yield decreases with the diminishing quantity of chlorine present in more regular way.

TABLE II. — Chlorination of Gold and Gold–Silver with Varying Quantities of Reagent

Ore, 5 A. T.; water, 150 c.c.; time, 5.5 hours.

Reagents.			Precious Metal. Milligrams.							
			Gold 10 : silver 0.		Gold 9 : silver 1.		Gold 8 : silver 2.		Gold 7 : silver 3.	
Bleaching powder.	Sulphuric acid.	Chlorine (calculated).	Gold in tailings.	Gold extraction.	Gold in tailings.	Gold extraction.	Gold in tailings.	Gold extraction.	Gold in tailings.	Gold extraction.
Grams.	Grams.	Grams.	mg.	Per cent.	mg.	Per cent.	mg.	Per cent.	mg.	Per cent.
14.0	21.0	2.8	0.04	99.6	0.18	98.2	0.30	96.3	4.18	40.3
10.5	15.0	2.1	0.14	98.6	0.30	96.7	4.98	37.8	4.40	37.1
7.0	10.5	1.4	0.75	92.5	0.90	90.0	5.90	26.5	5.10	27.1
6.5	9.75	1.3	5.48	45.2	5.37	40.3	6.23	22.1	6.08	13.2
6.0	9.0	1.2	7.44	25.6	6.84	24.0	6.28	21.5	6.15	12.1
5.0	7.5	1.0	7.70	23.0	7.09	21.2	6.42	19.8	6.36	9.1
3.5	5.25	0.7	8.06	19.4	7.48	16.9	6.85	14.4	n. d.	. .
2.5	3.75	0.5	8.26	17.4	7.59	15.7	7.12	11.0	n. d.	. .
1.0	2.0	0.2	8.56	14.4	7.99	11.2	7.48	6.5	n. d.	. .

TABLE III. — BROMINATION OF GOLD AND GOLD-SILVER WITH VARYING QUANTITIES OF REAGENT

Ore, 5 A. T.; water, 150 c.c.; time, 5.5 hours.

Reagents.		Precious Metal. Milligrams.							
		Gold 10 : silver 0.		Gold 8 : silver 2.		Gold 7 : silver 3.		Gold 6 : silver 4.	
Bromine.	Bromine.	Gold in tailings.	Gold extraction.	Gold in tailings.	Gold extraction.	Gold in tailings.	Gold extraction.	Gold in tailings.	Gold extraction.
c.c.	Grams.	mg.	Per cent.	mg.	Per cent.	mg.	Per cent.	mg.	Per cent.
3.0	8.97	0.08	99.2	0.18	97.8	0.16	97.7	4.56	24.0
2.0	5.98	0.18	98.2	0.20	97.5	1.48	78.9	4.92	18.0
1.5	4.48	0.34	96.6	0.24	97.0	3.00	57.1	5.18	13.7
1.0	2.99	0.68	93.2	0.58	92.8	3.70	47.2	5.16	14.0
0.8	2.60	0.78	92.2	1.88	77.6	4.40	37.1	5.16	14.0
0.7	2.10	6.58	34.2	6.02	24.8	5.95	15.0	n. d.	. .
0.5	1.5	7.62	23.8	6.56	18.0	6.46	7.7	n. d.	. .

Observations made with the flasks during the chlorinating tests are recorded in Table IV.

TABLE IV. — OBSERVATIONS MADE DURING CHLORINATION-TEST

Chlorine in 150 c.c. water.	Extraction of gold.	Color of solution.	Odor of solution.	Pressure of solution.
Grams.	Per cent.			
2.8	99.6	Deep yellow	Very strong	Strong
2.1	98.6	Deep yellow	Strong	Strong
1.4	92.5	Deep yellow	Medium	Strong
1.3	45.2	Yellow	Medium	Medium
1.2	25.6	Yellow	Medium	Medium
1.0	23.0	Pale yellow	Slight	Weak
0.7	19.4	Pale yellow	None	None
0.5	17.4	Almost colorless	None	None
0.2	14.4	Colorless	None	None

Gay-Lussac (see Table I) has shown that under atmospheric pressure and a temperature of 17° C. 1 c.c. of water can dissolve only 0.0075 g. of chlorine. In order to obtain the supersaturation required for a good extraction, it is necessary to have a "strong" pressure in the revolving-jar. When the pressure falls to "medium" there is a decided diminution in the yield of gold. This agrees with the experiences made in practice, where it has been found that pressure of free chlorine is absolutely necessary for a satisfactory extraction, *i.e.*, one of over 90 per cent. As the solution of chlorine in water, according to the law of Henry, increases with the pressure, one might be led to believe that very high pressures of free chlorine would increase the extraction of the gold; but this has been found not to be the case, as, *e.g.*, at Deloro, Canada,[1] no better results were obtained with 10- than with 60-pound pressure. The essential point was to have at first sufficient pressure of chlorine (10 to 15 pounds) that at the end of the operation (after two hours) there might be some left (3 pounds and less) to maintain the supersaturation of the solvent. The experimental data and results from large-scale work show that a satisfactory extraction of gold in barrel-chlorination can be obtained only by having supersaturated solution of chlorine in water; this requires a certain pressure, varying with the character of the ore, and has to be determined for every case.

In chlorinating the alloy of nine parts gold with one part silver, the extraction with 2.8 g. of chlorine falls 1.4 per cent.; with 2.1 g., 2.1; with 1.4 g., 2.5; and with 1.3 g., 4.9 per cent.; the decrease in yield growing with the diminishing grams of chlorine. With smaller quantities of chlorine, from 1.2 to 0.2 g., there is no such regularity.

With the alloy of gold eight parts and silver two parts, the supersaturated solution with 2.8 g. of chlorine shows only a small decrease of 0.7 per cent. in the gold dissolved. The solution with 2.1 g. of chlorine has its dissolving power diminished by 20.1 per cent., that with 1.4 g. of chlorine by 52.2 per cent.; that with 1.3 g. of chlorine falls off less, viz., 18.2 per cent.; it loses its previously isolated position and unites with the extremely low extractions of solutions with 1.2 to 0.2 g. chlorine.

With the alloy of gold seven parts and silver three parts, the solution with 2.8 g. of chlorine succumbs to the influence of silver, dissolving only 40.3 per cent. of the gold.

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[1] Engineering and Mining Journal, October 29, 1887, p. 309.

The data show that a supersaturated solution of chlorine in water acts more strongly than one that is merely saturated, that a supersaturated solution can extract a satisfactory percentage of gold from a gold-silver alloy containing as much as 20 per cent. of silver, and that with the decrease of chlorine below a certain amount (2.1 g.), and the increase of silver above 10 per cent., the extraction of gold falls off quickly.

The results of bromination in Figure 3 show that bromine also is an efficient solvent for gold, giving extractions of 99.8, 98.2, 96.6, 93.2, and 92.2 per cent. with solutions of 8.97, 5.98, 4.48, 2.90, and 2.60 g. of bromine in 150 c.c. of water; when the bromine present sinks to 2.1 g. the yield in gold falls quickly to 34.2 per cent., and then diminishes more gradually.

Observations made with the flasks during the brominating tests are recorded in Table V.

TABLE V. — OBSERVATIONS DURING BROMINATION-TEST

Bromine in 150 c.c. water.	Extraction of gold.	Color of solution.	Odor of solution.	Pressure of solution.
Grams.	Per cent.			
8.97	99.2	Dark-red	Strong	None
5.98	98.2	Dard-red	Strong	None
4.48	96.6	Dark-red	Strong	None
2.99	93.2	Dark-red	Slight	None
2.6	92.2	Dark-red	None	None
2.1	34.2	Light-red	None	None
1.5	23.8	Pale-red to yellow	None	None

The experiments of Dancer[1] show that at 15° C., ordinary temperature, saturated bromine water contains 3.22 per cent. of bromine; a saturated solution of 150 c.c. of water contains 4.839 g. of bromine. The tests show that a solution with as little as 2.6 g. of bromine dissolves more than 90 per cent. of the gold when silver is absent.

The presence of 20 per cent. of silver in the gold does not make more than 1 per cent. difference in the extraction in the first four tests with 8.97, 5.98, 4.48, and 2.99 g. of bromine; the fall begins with

[1] See *ante*.

2.6 g. of bromine, which dissolve 77.6 per cent. of gold, while in the absence of silver the same amount of bromine gives an extraction of 92.2 per cent.

With an alloy of seven parts gold and three parts silver, only the solution with 8.97 g. of bromine holds its own, giving a yield of 97.7 per cent.; the other solutions show diminishing extractions corresponding with the smaller amounts of bromine present.

With an alloy of six parts of gold and four parts of silver, the strongest solutions are similar to the weaker ones in their low percentages of extraction.

The data show that 150 c.c. water containing only 1.93 g. of bromine give a satisfactory extraction (92.8 per cent.) of gold from an alloy of gold with as much as 20 per cent. of silver, and that the extraction-figure is raised only 4.7 per cent. by doubling the amount of bromine.

The comparison of the dissolving-effects of chlorine and bromine upon pure gold and upon gold alloyed with different amounts of silver can be seen in Figure 3, but is more clearly illustrated in Figure 4.

Comparing curve I (chlorine and pure gold) with curve II (bromine and pure gold), it is seen that with concentrated solutions (2.8 g. of Cl equivalent to 6.0 g. of Br) chlorine is a slightly stronger solvent than bromine; as the solutions become less concentrated the dissolving power of chlorine falls more quickly than that of bromine, until at 1.58 g. chlorine (equivalent to 3.4 g. of bromine) the power of the two is the same. With further dilution to 1.20 g. of chlorine, bromine is a much better solvent than chlorine; when the dilution is carried very far, the percentages of extraction by the two solvents come again nearer together, but bromine always remains the more efficient of the two.

Curve III shows that the extraction of gold from an alloy of gold nine parts and silver one part by means of chlorine is but little affected by the presence of 10 per cent. of silver; that this is still less the case with bromine can be inferred from the bromination curves in Figure 3, where pure gold and gold with 20 per cent. of silver are connected by straight lines.

Coming to the alloy of eight parts of gold and two parts of silver, the harm done by the silver on the extraction with chlorine (curve IV) is marked, while with bromine it has very little effect. While with 2.8 g. of chlorine the extraction of gold is diminished only 2.1 per cent., it falls quickly and regularly with dilution of the solvent to 22.1 per cent. until 1.3 g. has been reached, and then falls suddenly

to an insignificant figure. With bromine, dilution from 6 to 3 g. hardly affects the result, and a further addition of water only very little. Thus bromine again is the better solvent in the presence of silver.

Curves VI and VII, representing the treatment of an alloy of seven parts of gold and three parts of silver, with chlorine and bromine, show how seriously the extraction of gold is affected by the presence of such large proportions of silver, but the extractions of bromine are always better than those of the equivalent quantities of chlorine.

Curve VIII, standing for the alloy of six parts of gold and four parts of silver, finally shows how even bromine loses its dissolving power when it meets such large proportions of silver.

The curves bring out the additional interesting fact that changes in the degree of concentration of chlorine, as well as of bromine, do not make a very decided difference in the percentage of extraction with pure gold or gold with 10 per cent. of silver as long as with 150 c.c. of water 1.4 g. of chlorine, equivalent to 3 g. of bromine, is not overstepped as the lower limit. With gold containing more than 10 per cent. of silver, a slight decrease in the concentration makes a very decided difference in the extraction until 1.2 g. is reached with chlorine, and 2.1 g. with bromine. If the solutions are further diluted, the effect of an increase in silver is not so very marked.

ROASTING AND MAGNETIC SEPARATION OF A BLENDE-MARCASITE CONCENTRATE[1]

By H. O. HOFMAN and H. L. NORTON

I. Introduction

Zinc smelters in the central western states have established a very high standard of purity for blende-concentrates, viz., zinc 60, iron less than 3, and lead less than 1 per cent. The very low percentage of iron is made possible by the blende containing less than 0.5 per cent. of isomorphous iron sulphide and by the sparing occurrence of pyritic material in the large blende-deposits of southwestern Missouri and southeastern Kansas. The blende in these districts occurs in Sub-carboniferous limestone, and is associated with chert, residual clay, calcite, pyrite or marcasite, and bitumen. The different minerals are coarse and therefore readily separated by mechanical washing from the blende, with the exception of pyrite and marcasite, as blende has a specific gravity of from 3.9 to 4.1; marcasite, from 4.85 to 4.90; and pyrite, from 4.95 to 5.10. The common procedure of dressing the ores[2] is to crush in a breaker, size in a trommel with 0.5-inch holes, pass the oversize through roughing-rolls, and then jig the ore, now reduced to 0.5 inch maximum size, in roughing multiple-sieve jigs. The products of these are waste tailings, side-discharge coarse concentrates, side-discharge coarse middlings, and bottom-discharge fine middlings. The coarse concentrates are sent to the market. The coarse middlings are crushed in middling-rolls and brought back into the system by feeding into the main trommel. The fine middlings are cleaned upon finishing-jigs. Any pyrite or marcasite present follows the blende and increases the percentage of iron above permissible limits. Several processes[3] based upon roasting for porosity (Schulls-

[1] Reprinted from Transactions of the American Institute of Mining Engineers, Lake Superior meeting, September, 1904.

[2] Ore-Dressing, by R. H. Richards. New York, 1903, p. 900.

[3] Production and Properties of Zinc, by W. R. Ingalls. New York, 1902, p. 255; Ore-Dressing, by R. H. Richards, pp. 790, 880.

burg, Wisconsin; Åmmeberg, Sweden), heating for decrepitation (Heusschen Process), or disintegration followed by screening (Lintorf, Prussia), have been used for separating blende and pyrite, but they have all been, or will be, replaced by magnetic separation. Pyrite, marcasite, and blende are diamagnetic; blende may be feebly paramagnetic, the attraction depending upon the percentage of isomorphous iron sulphide it contains. In order to separate pyrite or marcasite from blende running low in iron, the former has to be made magnetic. This can be done in two ways, by converting the disulphide of iron into magnetic oxide or magnetic sulphide. In the work to be discussed both methods were tried.

II. The Ore and the Outline of the Experimental Work

The ore used in the experiments was a coarse concentrate of about 0.5-inch size from the mines of the Alexandra Mining Company, Carterville, Missouri, furnished by the superintendent, Mr. T. F. Lennan. It consisted of light-colored resinous blende (rosin jack), marcasite, and chert. The chemical analysis gave Zn, 35.94, and Fe, 18.77 per cent. Calculating all the iron as marcasite, the rational analysis would be, blende, 53.57; marcasite, 40.22; and gangue, 6.21 per cent.

Preliminary experiments having shown that the ore as received, *i. e.*, 0.5-inch material, was too coarse for the proposed work, an 8-mesh screen was chosen for the limiting size, as this appeared to work well and as it is the one best suited for roasting blende. In order to study the behavior of ore of smaller size, a 20-mesh screen was selected as the limit, because in crushing the 0.5-inch ore through an 8-inch sieve a very large quantity was found to be fine enough to pass through a 20-mesh screen. A series of experiments was then made on those two sizes. The operations were: 1. Crushing to required size. 2. Roasting above the ignition-point of marcasite, but below that of blende, and magnetic separation. 3. Roasting as under 2, sizing, and magnetic separation of sized product. 4. Sizing crushed ore, roasting, and magnetic separation of sized material. 5. Analytical determination of zinc and iron.

III. Apparatus and Methods of Analysis

The apparatus used in the experiments were two heating-furnaces with Le Chatelier pyrometers and two electro-magnets.

An electric heating-furnace, similar to the retort furnace described by Hofman [1] in a paper read at the Lake Superior meeting of the Institute of Mining Engineers, September, 1904, served to determine the ignition-points of marcasite and blende. The roasting operations were carried on in 5-inch roasting-dishes heated in a gas muffle-furnace, made by the American Gas Furnace Company, New York, with a muffle 12 inches long, 6.75 inches wide, and 3.75 inches high. While one charge was being heated in the muffle, a dish charged with ore was warmed at the front so that it might be brought quickly to the muffle-temperature when the ore was to be roasted.

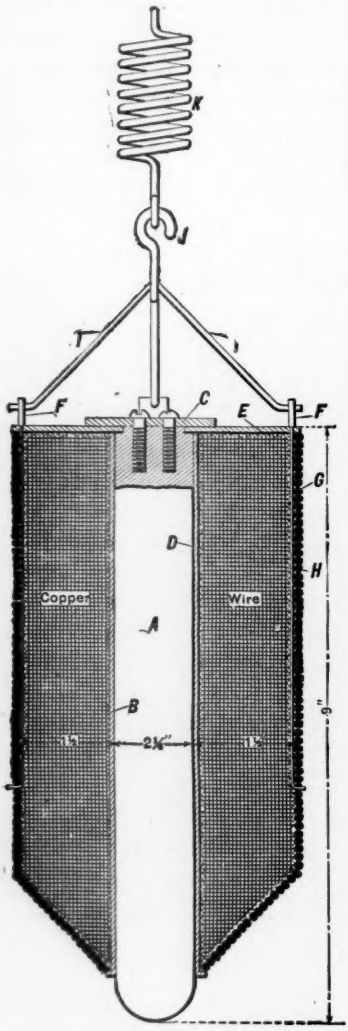

FIG. 1.—SINGLE-POLE MAGNET

In the measurement of temperature the two leads of the Le Chatelier pyrometers, wound with asbestos thread, were held in a porcelain tube. The thermocouple protruding at one end was about at the level of the ore-charge when the porcelain tube was lying on the floor of the muffle close to the roasting-dish. In this position the temperatures were taken. When the muffle had been brought to the desired temperature, it required very little regulating of the gas and air supply to hold it there.

For the magnetic separation of the roasted ore, two electro-magnets constructed for laboratory purposes, by Prof. R. H. Richards, were used, one a single-pole, the other a double-pole. The single-pole magnet is shown in Figure 1. The core, *A*, a cylinder of soft Norway iron, fits

[1] "The Decomposition and Formation of Zinc Sulphate by Heating and Roasting," TECHNOLOGY QUARTERLY, 1904, 17, p. 333.

into a brass tube, *B*, carrying the coils of copper wire; it is rounded at one end and screwed to a brass disk, *C*, at the other. It is enclosed by three layers of paper, *D*. There are 9,240 turns of double cotton-covered No. 21 copper wire, equal to a length of 8,100 feet. At

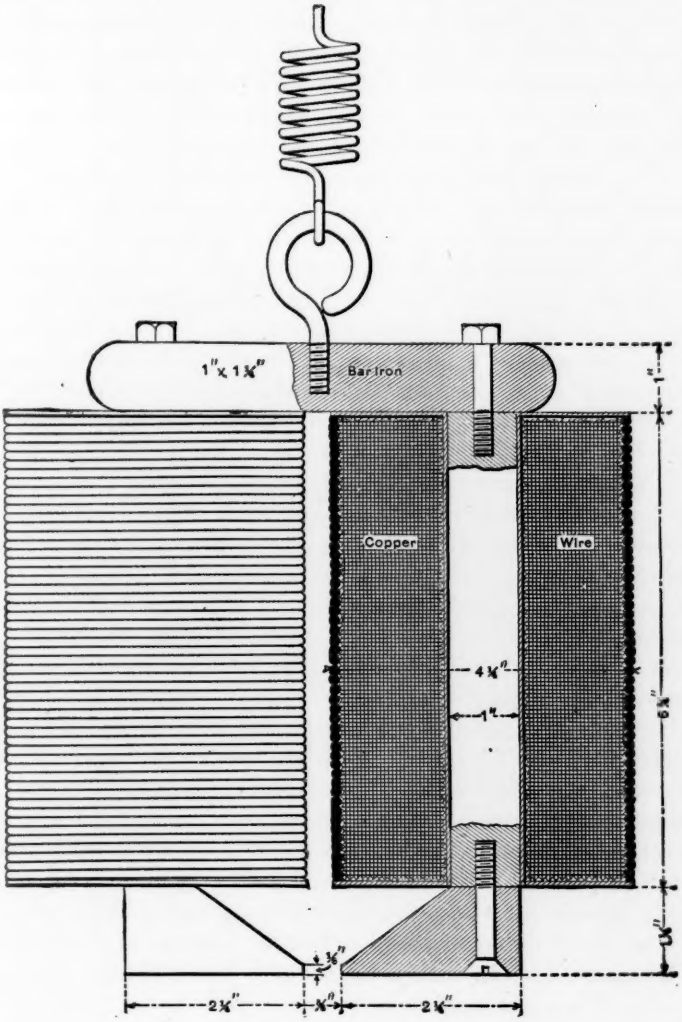

FIG. 2.— DOUBLE-POLE MAGNET

the top the coil is held in place by the brass disk and protected by three rings of paper, *E*; at the bottom, tape is wound in with the wire to prevent the coils from slipping. In winding the wire downward, four pieces of linen tape, 4 inches long and 0.25 inch wide, are placed for a distance of 2 inches on the sides of the core. When covered with wire, the tape was bent upon itself, and the free ends now covered with wire in winding upward. Thus each winding is held in place near the bottom of the core by four loops of tape and prevented from slipping. The winding is such that a current of 0.8 ampere at a pressure of fifty volts gives the maximum of magnetic lines the core can carry without undue heating. The magnet is suspended by four strips of brass, *F*, held in place by $\frac{3}{16}$-inch twine (tarred marline), *G*, wound closely around the coils previously covered with three layers of paper, *H*. The twine forms at the same time a protective casing for the magnet. Each strip has an eye near the upper end, a stout wire, *I*, is passed through it, the four wires are wound together and bent to a hook, *J*, and hung on a steel spring, *K*, suspended by an iron rod from the ceiling.

The double-pole magnet, shown in Figure 2, has two cores of soft iron joined at the top by a yoke of cast iron; the pole-shoes, with faces 1 by $\frac{1}{8}$ inch, are screwed to the bottoms of the cores, leaving an air-gap $\frac{5}{8}$ inch long between the north and south poles. The magnet is suspended by a screw-eye from a spring in the same manner as the single-pole magnet. Each core is wound with 5,000 feet of the same wire as the single-pole magnet, making 6,760 turns. The coils are held in place at top and bottom by brass rings and are protected by layers of paper and tarred marline. The saturation-point is the same as that of the single-pole magnet.

The attractive power of a magnet varies with the number of lines of force that pass through it. With the single-pole magnet there is the greatest scattering of lines of force, with the double-pole magnet the greatest concentration, hence for a given electric current the attraction per square centimeter of field in a single-pole magnet is much smaller (about 60 per cent.) than in the double-pole magnet, as long as the air-gap between the two poles is not too large.

The current for the magnets is taken by a shunt from the 110-volt electric-light main. In order to reduce it to the required strength, an incandescent lamp of eight candle power is placed in the circuit. From the magnet the current passes through a Weston direct-reading ammeter

back to the main. A switch is placed in the circuit to permit the current to be turned on and off.

In a test the ore was spread out on a piece of glazed paper, the current turned on, the single-pole magnet passed to and fro over the ore with raising and lowering, and then moved to one side, the current switched off, and the adhering ore dropped on a paper. Another layer of ore was then spread over the first glazed paper, and the operations repeated until a batch had been treated. The first magnetic concentrates were then retreated until they had been freed from the non-magnetic particles that had been carried along mechanically. As a rule the tailings from the single-pole magnet were treated with the double-pole magnet, the manipulation being the same as in the first operation.

The zinc in the ore and the tailings was determined by titrating with potassium ferrocyanide as worked out by von Schulz and Low in 1900.[1] With the magnetic concentrates, which run high in iron and are not decomposed by treatment with nitric acid and potassium chlorate, solution with nitrohydrochloric acid had to be substituted. The iron was converted into sulphate and titrated with potassium permanganate.

IV. Experiment with 8-mesh Material

1. *Crushing.* — The ore as received, of 0.5-inch size, was crushed in a Hendrie and Bolthoff sample-grinder to pass through an 8-mesh sieve. The screen-analysis of the product is given in Table I.

TABLE I. — Screen-Analysis of 8-mesh Ore

Size of screen.	Grams.	Per cent.
Through 8- and on 12-mesh	54	33.1
Through 12- and on 16-mesh	18	11.0
Through 16- and on 20-mesh	16	9.8
Through 20-mesh	75	46.0
Totals	163	99.9

The data in Table I show that 46 per cent. of the ground ore was fine enough to pass through a 20-mesh sieve. It is this figure which decided the choice of 20-mesh material for the tests on fine ore.

[1] Production and Properties of Zinc, by W. R. Ingalls, p. 99.

2. *Roasting and Magnetic Separation of Unsized Material.*— Before any roasting could be undertaken, it was necessary to determine the limits of temperature which had to lie above the ignition-point of marcasite and below that of blende. The two points were found to be 378° C. for marcasite and 600° C. for blende. The first tests were planned to keep the time constant and to vary the temperature. The leading facts and results are brought together in Table II.

TABLE II.—EXPERIMENTS WITH UNSIZED 8-MESH MATERIAL

	Roasting.							Magnetic Separation.									
									Heads.						Tailings.		
									Single-pole.			Double-pole.					
No. of sample.	Raw ore.	Depth of charge at centre.	Roasted ore.	Loss in roast.	Loss in roast.	Temperature of muffle.	Duration of roast.	Weight taken.	On weight taken.	On raw ore.		On weight taken.	On raw ore.		On weight taken.	On raw ore.	
	Gr.	In.	Gr.	Gr.	%	°C.	Min.	Gr.	Gr.	%	%	Gr.	%	%	Gr.	%	%
1	200	⅝	175	25	14.3	400	105	175	. .	. .	. .	4	2.2	2.0	171	97.8	85.5
2	200	⅝	168	32	19.0	410	110	168	. .	. .	. .	5	2.9	2.5	163	97.1	81.5
3	200	⅝	170	30	17.7	460	120	170	. .	. .	. .	19	11.2	9.5	151	88.8	75.5
4	200	⅝	165	35	21.3	490	125	165	7	4.2	3.5	16	9.7	8.0	142	86.1	71.0
5	200	⅝	159	41	25.9	560	120	159	12	7.5	6.0	20	6.3	10.0	127	86.2	63.5
6	200	⅝	158	42	26.6	620	120	158	17	10.8	8.5	19	12.0	9.5	122	77.2	61.0

In the six tests made to convert by long-time roasts marcasite into magnetic iron oxide, the time given to roasts Nos. 3, 5, and 6 was 120 minutes; roast No. 4 was accidentally continued five minutes longer than the other three; roasts Nos. 1 and 2, serving as feelers, lasted only 105 and 110 minutes respectively. The temperatures show a range of from 400 to 620° C. The rise above 600° C. was due to the heat generated in the burning of marcasite; it caused some blende to become superficially oxidized. The concentration-tests show that at a temperature ranging from 400 to 460° C. the ore is not sufficiently altered to be attracted by the single-pole magnet. With a rise of temperature the extraction begins with 3.5 per cent. and increases to the moderate figure of 8.5 per cent., when the limit of temperature set has been overstepped.

The double-pole magnet, within the range of from 400 to 460° C., draws out from 2.0 to 9.5 per cent. of magnetic material which was

not acted upon by the single-pole. The higher temperatures, 460° and 620° C., give an additional yield of from 8 to 10 per cent. to that obtained by the single-pole magnet, but at best the total extraction of 18 per cent. is very unsatisfactory. Most of the ore removed by the magnet was fine; coarse particles could be moved about on the paper, but not made to adhere to the magnet. The results ought, therefore, to be improved by fine-crushing. The screen-analyses of the roasted products given in Table III show that the 46 per cent. of material finer than 20-mesh size in the raw ore has been increased to about 60 per cent. in the roasted ore. This must be attributed to decrepitation. The 6 or 7 per cent. of ore which remained on the 8-mesh sieve find their explanation in the swelling of particles during the roast.

TABLE III. — SCREEN-ANALYSIS OF ROASTED 8-MESH MATERIAL

No. of sample.	Weight taken.	On 8-mesh.		On 12-mesh.		On 16-mesh.		On 20-mesh.		Through 20-mesh.	
	Grams.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.	Grams.	Per cent.
1	168	7	4.1	23	13.7	16	9.5	15	8.9	107	63.7
2	160	6	3.7	27	16.9	14	8.7	15	9.3	98	61.2
3	158	7	4.4	27	17.1	14	8.8	14	8.8	96	60.8
4	154	7	4.5	23	14.9	13	8.4	14	9.0	97	63.0
5	152	6	3.9	33	21.7	15	9.8	16	10.5	82	53.9
6	161	7	4.3	29	18.0	12	7.4	14	8.7	98	60.8

V. EXPERIMENTS WITH 20-MESH MATERIAL, UNSIZED

1. *Crushing.* — The 8-mesh material was ground to pass a 20-mesh screen in the same manner as the original ore. The sizes obtained in the operation are given in Table IV. It shows that of the ore 45.5 per cent. was coarser than a 40-mesh, while 33.5 per cent. passed through an 80-mesh screen.

TABLE IV. — SCREEN-ANALYSIS OF 20-MESH ORE

Size of screen.	Grams.	Per cent.
Through 20- and on 40-mesh	89	45.5
Through 40- and on 60-mesh	34	17.0
Through 60- and on 80-mesh	10	5.0
Through 80-mesh	67	33.5
Total	200	100.0

2. *Roasting and Magnetic Separation of Unsized Ore.* — As the results in Table II had pointed to the conclusion that a higher temperature was more favorable to magnetization than a lower one, the former was chosen. The roasts were carried on at the constant temperature of 600° C., and the time gradually reduced from 120 to 1.25 minutes. The weight of a charge was 100 grams, which gave a layer 0.5 inch deep in the centre of the roasting-dish. In the roasts lasting longer than five minutes, the temperature-readings were taken every five minutes, and the ore was stirred every two minutes; in the roasts lasting five minutes or less, the temperature was read at the beginning and the end of the roast, and the ore stirred continuously. The appearance of the roasted ore varied with the time it had been exposed to heating; that from the long-time roasts was brownish, due to the more perfect oxidation; that from the short-time roasts black, on account of the partial conversion of iron disulphide into magnetic monosulphide.

After the completion of the roast, the ore was weighed, a sample taken for chemical analysis, and the rest subjected to the single-pole and then to the double-pole magnet. A small portion of the zinc contained in the magnetic heads from the single-pole and especially from the double-pole magnet was not carried along mechanically, but was itself attracted by the magnet, showing that the very small quantity of iron sulphide contained in the light-brown resinous blende was sufficient to cause this to show some magnetic property. The results are assembled in Table V, which is best made clear by following through one test. In test No. 9, *e.g.*, 100 grams of raw ore, spread over the roasting-dish, gave a layer 0.5 inch thick in the centre of the dish. The ore was roasted for 1.25 minutes at a temperature of 600° C. The roasted ore weighed 95 grams, thus losing 5 per cent. in weight by the operation. From the 95 grams roasted ore, 15 grams were reserved for chemical analysis, leaving 80 grams for magnetic treatment.

Table V, however, gives only the data calculated to the basis of the total weight of the roasted ore, *i.e.*, 95 grams. The single-pole magnet took out 23.7 grams, the double-pole magnet 15.5 grams, giving a total of 39.2 grams of magnetic material, and leaving 55.98 grams of tailings. The percentage of zinc of the single-pole product was found by calculation: the total quantity of zinc present in the raw or roasted ore was 35.94 grams. The tailings gave by analysis 55.98 per cent. of zinc; they contained, therefore, $0.5598 \times 55.9 = 31.29$ grams of zinc. The

TABLE V.— EXPERIMENTS WITH 20-MESH MATERIAL (35.94 PER CENT. ZN), UNSIZED

Roasting.							Magnetic Separation.														
							Heads.										Tailings.				
							Single-pole.				Double-pole.				Total.						
No. of sample.	Raw ore.	Depth of charge.	Roasted ore.	Loss of weight in roast.	Temperature of muffle.	Duration of roast.	Calculated on weight of roasted ore.	Zinc, calculated.	Weight, zinc.	On zinc in the raw ore.	Calculated on weight of roasted ore.	Zinc by analysis.	Weight, zinc.	On zinc in the raw ore.	Calculated on weight of roasted ore.	Weight of zinc.	On zinc in the raw ore.	Calculated on weight of roasted ore.	Zinc by analysis.	Weight of zinc.	On zinc in the raw ore.	Iron by analysis.
	Gr.	In.	Gr.	%	° C.	Min.	%	Gr.	Gr.	%	Gr.	%	Gr.	%	Gr.	Gr.	%	Gr.	%	Gr.	%	%
1	100	0.5	78	22	600	120.0	0.0	0.0	0.0	0.0	32.9	11.04	3.63	10.10	32.9	3.63	10.10	45.1	71.17	32.10	89.23	3.78
2	100	0.5	81	19	600	80.0	0.0	0.0	0.0	0.0	31.3	2.36	0 74	2.05	31.3	0.74	2.05	50.1	66.94	33.54	93.30	2.78
3	100	0.5	83	17	600	60.0	4.3	0.0	0.0	0.0	26.9	7.20	1.94	5.40	31.2	1.94	5.40	51.8	65.69	34.02	94.64	2.81
4	100	0.5	86	14	600	30.0	15.6	0.0	0.0	0.0	20.1	19.58	3.94	10.96	35.7	3.94	10.96	50.3	64.52	32.45	90.28	1.57
5	100	0.5	87	13	600	15.0	20.9	0.0	0.0	0.0	15.4	29.16	4.49	12.49	36.3	4.49	12.49	50.7	64.36	32.63	90.78	1.32
6	100	0.5	89	11	600	10.0	29.7	1.91	0.67	1.86	10.4	37.41	4.26	11.86	40.1	4.93	13.72	47.9	64.76	31.01	86.28	0.90
7	100	0.5	89	11	600	5.0	30.4	2.86	0.87	2.42	10.2	35.24	3.56	9.90	40.6	4.43	12.32	48.5	64.97	31.51	87.68	0.90
8	100	0.5	92	8	600	2.5	23.8	2.27	0.54	1.50	14.8	26.73	3.93	10.94	38.6	4.47	12.44	53.5	58.53	31.47	87.56	5.13
9	100	0.5	95	5	600	1.25	23.7	2.57	0.61	1.69	15.5	26.29	4.04	11.25	39.2	4.65	12.94	55.9	55.98	31.29	87.06	7.05

double-pole magnetic product gave 26.29 per cent. of zinc and contained $0.2629 \times 15.5 = 4.04$ grams of zinc. The single-pole concentrates, therefore, contained $35.94 - (31.29 + 4.04) = 0.61$ grams, which corresponds to $\frac{0.61}{23.7} \times 100 = 2.57$ per cent. of zinc. The distribution of the zinc in the raw ore among the three products was next calculated and found to be, in the single-pole product, $\frac{0.61}{35.94} \times 100 = 1.69$ per cent.; in the double-pole product, $\frac{4.04}{35.94} \times 100 = 11.25$ per cent., or a total of 12.94 per cent.; in the tailings, $\frac{31.29}{35.94} \times 100 = 87.06$ per cent. Thus 87.06 per cent. of the total quantity of zinc was recovered in the tailings which by analysis gave 7.05 per cent. of iron.

Reviewing the data in Table V as a whole, it is seen that when the ore is roasted from 80 to 120 minutes nothing is extracted by the single-pole magnet. As the time of roasting decreases, the ore becomes more and more magnetic until with a five-minute roast a maximum of 30.4 grams is obtained. With roasts of shorter duration the quantity extracted decreases again. Using the double-pole after the single-pole magnet, 32.9 grams are taken out with the 120-minute roast, the quantity removed diminishes with the time of the roast, until with a five-minute roast the minimum is reached with 10.2 grams. Reducing the time below five minutes again increases the quantity of concentrate. The results of ten-minute roasts differ little from those obtained in roasting five minutes.

As far, then, as quantity of material extracted is concerned, a roast ranging from five to ten minutes gives the best results, as during this period the ore becomes sufficiently magnetic to allow a maximum to be removed by the single-pole magnet or by a double-pole magnet of lower magneto-motive force. The quality of the products, *i. e.*, the percentage of zinc remaining in the concentrates, which is lost, and in the tailings, which is recovered, and the percentage of iron retained by the tailings are plotted in Figure 3 from the data in the table. The abscissa gives the duration of the roasts in minutes; on the ordinate are inscribed the percentages in four different scales to permit bringing the whole together in a single sheet and thus facilitate comparison. In roasting the ore 120 minutes, the single-pole magnet took out nothing, the double-pole concentrates carried along with them 10.10 per cent. of the zinc contained in the ore, while in the tailings

there was recovered 89.23 per cent.; the tailings assayed 3.78 per cent. of iron. The quantity of zinc retained by the double-pole magnet decreased to 2.05 per cent. with the shortening of the time of roasting to eighty minutes; it then again increased until a maximum of 12.49 per

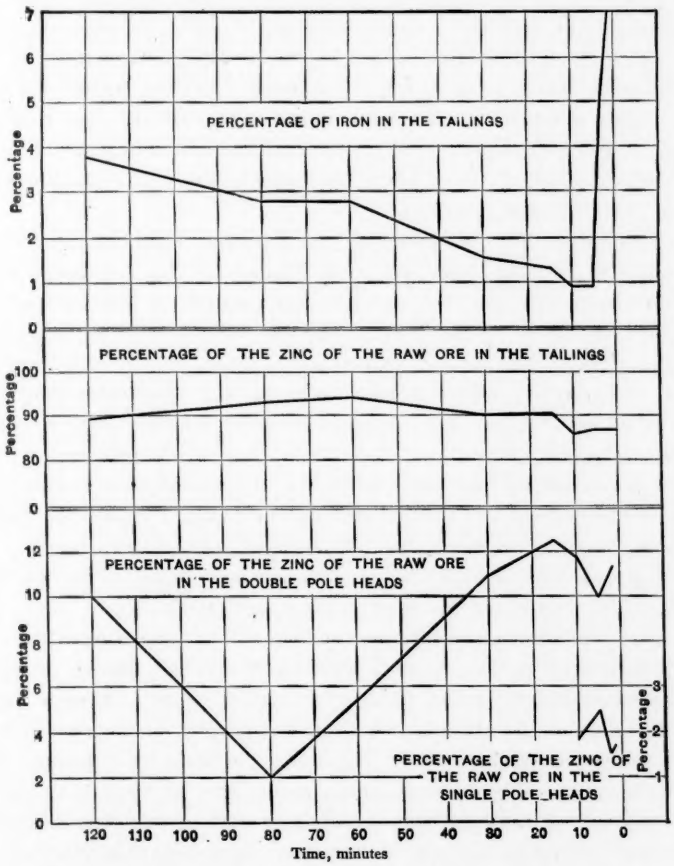
PERCENTAGE OF IRON IN THE TAILINGS
Percentage
PERCENTAGE OF THE ZINC OF THE RAW ORE IN THE TAILINGS
Percentage
PERCENTAGE OF THE ZINC OF THE RAW ORE IN THE DOUBLE POLE HEADS
Percentage
PERCENTAGE OF THE ZINC OF THE RAW ORE IN THE SINGLE POLE HEADS
Percentage
120 110 100 90 80 70 60 50 40 30 20 10 0
Time, minutes

FIG. 3.—PRODUCTS FROM ROASTING AND MAGNETIC TREATMENT OF 20-MESH UNSIZED ORE

cent. was reached with fifteen minutes; this was followed by a second minimum of 10.2 per cent. with five minutes. The single-pole heads did not retain any zinc until the time of roasting had been reduced to ten minutes, when they held 1.81 per cent. of the total quantity of zinc;

at five minutes their zinc-content reached a maximum of 2.42 per cent., which is followed by a minimum of 1.5 per cent. at 2.5 minutes.

The tailings show an approximately corresponding variation in zinc, ranging from 86.28 to 94.64 per cent., and a steadily diminishing iron-content until the five-minute roast has been reached with 0.9 per cent. of iron, when there is a sudden increase. The most favorable result for the single-pole magnet, 1.50 per cent. of the total quantity of zinc, is obtained with a roast lasting 2.5 minutes; with the double-pole magnet eighty minutes give the minimum of zinc, 2.05 per cent.; the tailings furnish the highest yield in zinc, 94.64 per cent., when the roast is prolonged for sixty minutes, but unfortunately the percentage of iron, 2.81 per cent., is high.

Combining the four points of view, the best quality of product is obtained in roasting from five to ten minutes; the single-pole heads retain about 2.25 per cent. of the total quantity of zinc, the double-pole heads about 11 per cent., and the tailings collect from 86 to 87 per cent. The raw ore, with 35.94 per cent. of zinc and 18.77 per cent. of iron, has been enriched to a market blende assaying 64.8 per cent. of zinc and 0.9 per cent. of iron, and the yield of zinc is from 86 to 87 per cent.

A screen-analysis of the roasted ore, of the magnetic concentrates, and of the tailings was carried through in order to study the changes in size, etc., the ore (see Table IV) and the tailings had undergone in roasting, and to find what special sizes had been attracted by the magnets. The results are given in Table VI, in which Nos. 1 to 9 correspond to the similar designations in Table V. Comparing Tables IV and VI, it is seen that about 3 per cent. of the ore, during the roast, increased sufficiently in size so as not to pass through a 20-mesh screen. While with the raw ore 45.5 per cent. was caught on a 40-mesh sieve, the roasted ore yielded only 35 per cent.; the material remaining on a 60-mesh and passing through an 80-mesh sieve is about the same in both cases, 17 and 33 per cent.; while that held by the 80-mesh screen is smaller with the raw ore (5 per cent.) than with the roasted ore (9 per cent.). These changes are due to the decrepitation of the blende. Of the concentrates taken out by the single-pole magnet, about 45 per cent. is coarser than a 40-mesh, and about 35 per cent. finer than an 80-mesh sieve. With the double-pole magnet, a little less than 35 per cent. is coarser than a 40-mesh, and over 45 per cent. finer than an 80-mesh sieve. The tailings give similar figures for the

larger-size material; about 35 per cent. will be caught by a 40-mesh screen, while a smaller amount of fines, 33 per cent., passes through an 80-mesh screen.

TABLE VI. — Screen-Analysis of Roasted, Unsized 20-mesh Material

No. of sample.	Roasted Ore.											Magnetic Heads.								
												Single-pole.								
	Weight taken.	On 20.		On 40.		On 60.		On 80.		Through 80.		Weight taken.	On 40.		On 60.		On 80.		Through 80.	
	Gr.	Gr.	%	Gr.	%	Gr.	%	Gr.	%	Gr.	%	Gr.	Gr.	%	Gr.	%	Gr.	%	Gr.	%
1	71	2	3	24	34	14	19	7	9	24	34	. .	. .	. .	. .	. .	. .	. .	. .	. .
2	75	3	4	26	34	14	18	7	9	25	34	. .	. .	. .	. .	. .	. .	. .	. .	. .
3	77	2	3	27	35	14	18	7	9	27	35	4	. .	. .	. .	. .	. .	. .	. .	. .
4	77	4	5	27	35	16	20	7	9	23	30	14	5	36	1	7	2	12	6	43
5	79	2	2	26	33	16	20	7	9	28	34	19	9	46	4	21	1	5	5	26
6	78	3	3	29	36	15	19	6	8	25	32	26	12	46	4	15	1	4	8	30
7	79	3	3	29	35	15	19	5	8	26	33	27	11	41	5	14	1	4	9	33
8	81	2	2	28	34	14	17	8	7	29	35	21	10	47	3	14	1	5	7	33
9	80	2	2	29	36	15	18	7	9	26	32	20	8	40	4	20	1	5	6	30

TABLE VI. — Screen-Analysis of Roasted, Unsized 20-mesh Material. — *Continued*

No. of sample.	Magnetic Heads.									Tailings.								
	Double-pole.																	
	Weight taken.	On 40.		On 60.		On 80.		Through 80.		Weight taken.	On 40.		On 60.		On 80.		Through 80.	
	Gr.	Gr.	%	Gr.	%	Gr.	%	Gr.	%	Gr.	Gr.	%	Gr.	%	Gr.	%	Gr.	%
1	30	9	30	5	16	3	10	13	43	41	14	34	8	19	5	12	14	34
2	29	11	37	4	13	2	7	12	41	46	19	41	7	15	4	8	16	34
3	25	10	40	4	16	2	8	9	36	48	17	35	10	21	5	10	16	33
4	18	7	38	3	16	1	6	7	39	45	18	35	7	15	5	11	15	33
5	14	5	35	1	7	1	7	7	50	46	17	37	7	15	5	11	17	37
6	10	3	30	2	20	. .	. .	5	50	42	15	35	9	21	4	9	17	40
7	9	3	33	1	11	1	11	4	44	43	15	35	10	23	5	11	13	30
8	13	4	30	1	7	1	7	7	53	44	18	40	9	20	5	11	12	28
9	13	4	30	1	7	1	7	6	46	46	19	41	11	23	4	9	12	27

VI. Experiments with 20-mesh Material; Roasting, Sizing, and Magnetic Separation

The aim of this series of tests was to find out whether a better magnetic separation could be obtained with sized than with unsized material, as in the preceding experiments. Some of the experiments on 8-mesh unsized material (Table I) had shown that, while the fine particles were readily attracted by the magnet, the coarser ones could only be made to travel over the paper when the magnet was moved to and fro.

1. *Crushing.* — The ore used in the tests was taken from the same lot as that in the preceding work.

2. *Roasting, Sizing, and Magnetic Separation.* — In order to have enough material of the different sizes for magnetic treatment, it was necessary to use 300 grams. The sample was, however, roasted in three separate portions of 100 grams each, in order to have the same conditions as before as far as quantity was concerned. The temperature of the muffle was maintained at 600° C., and the time given to a roast reduced to five minutes, as the previous work had shown that this gave the best results. The loss in weight in roasting was 8 per cent.

Sizing the roasted ore gave the subjoined data.

TABLE VII. — Screen-Analysis of 20-mesh Material, Roasted

Size of screen.	Grams.	Per cent.
Through 20- and on 40-mesh	99.3	36
Through 40- and on 60-mesh	53.6	19
Through 60- and on 80-mesh	25.5	8
Through 80-mesh	96.8	35
Totals	275.2	98

The results are similar to those of Table VI. Of the ore 36 per cent. is coarser than a 40-mesh, and 35 per cent. finer than an 80-mesh screen.

The sized material was subjected first to the single-pole and then to the double-pole magnet as described in the preceding pages. The results obtained are assembled in Table VIII, which is put together on the same general lines as Table V, with the exception that the percentage of zinc of each of the three products had to be determined analytically, as any calculation was excluded by the circumstance that the total zinc present in a mesh-size was an unknown quantity.

TABLE VIII. — Work on 20-mesh Material, Roasted, Sized, and Separated

Weight from Table VII.	Magnetic Separation.																										
			Heads.																		Tailings.						
			Single-pole.						Double-pole.						Total.												
	Mesh-size.	Weight taken.		On weight taken.	On raw ore.	Zinc.	Weight, zinc.	On zinc in the raw ore.		On weight taken.	On raw ore.	Zinc.	Weight, zinc.	On zinc in the raw ore.		On weight taken.	On raw ore.	Weight, zinc.	On zinc in the raw ore.		On weight taken.	On raw ore.	Zinc.	Weight, zinc.	On zinc in the raw ore.	Iron.
%		Gr.	Gr.	%	%	%	Gr.	%	Gr.	%	%	%	Gr.	%	Gr.	%	%	Gr.	%	Gr.	%	%	%	Gr.	%	%	%
36	On 40	99.3	30.6	30.8	10.2	3.58	1.10	1.02	15.3	15.4	5.1	28.15	4.31	4.00	45.9	46.2	15.3	5.41	5.02	63.4	63.8	47.8	61.70	32.89	30.52	2.02
19	On 60	53.6	12.1	22.5	4.0	3.90	0.47	0.44	7.8	14.5	2.6	28.84	2.83	2.62	19.9	37.0	6.6	3.30	3.06	33.7	63.0	11.2	60.68	20.45	18.97	2.44
8	On 80	25.5	5.1	20.0	1.7	3.32	0.17	0.16	3 6	14.1	1.2	23.91	0.86	0.80	8.7	34.1	2.9	1.03	0.96	16.8	65 9	5.6	60.91	10.23	9.49	2.49
35	Through 80 .	96.8	31.1	31.5	10.4	12.29	3.82	3.54	22.8	23.5	7.6	31.39	7.16	6.64	53.9	55.0	17.9	10.98	10.18	42.9	45.0	14.3	54.74	23.48	21.78	5.42
Totals	. . .	. .	. .	. .	. .	. .	. .	5.16	. .	. .	. .	. .	. .	14.06	. .	. .	. .	. .	19.22	. .	. .	. .	.	. .	80.76	. .

Note. — The total quantity of zinc in raw ore equals (3 × 35.94) 106.92 grams.

An examination of Table VIII shows that a good separation was obtained with material too coarse to pass an 80-mesh screen. Thus, 40-mesh ore, which comprised 36 per cent. of the ore treated, gave tailings running 61.70 per cent. of zinc and 2.02 per cent. of iron with a loss of only 5.02 per cent. of the total quantity of zinc. Material of 60- and 80-mesh sizes gave tailings of a similar tenor in zinc with an even smaller loss in total zinc. The work upon ore finer than an 80-mesh screen gave unsatisfactory results. Forming by weight 35 per cent. of the ore subjected to magnetic treatment, the tailings could not be brought to run higher than 54.74 per cent. of zinc and lower than 5.42 per cent. of iron, accompanied by a loss in the concentrates of 10.18 per cent. of the zinc present.

The sample of 300 grams of raw ore contained (3 × 35.94) 106.92 grams of zinc. Of this, 80.76 per cent. was recovered in the tailings and 19.22 per cent. lost in the concentrates, 5.16 per cent. in those of the single-pole, and 14.06 per cent. of the double-pole, the main loss being due to material finer than an 80-mesh sieve. The results are inferior to those obtained with unsized roasted ore. The plan of sizing roasted ore before treatment with the magnet is not advantageous.

VII. Experiments with 20-mesh Material; Sizing, Roasting, and Magnetic Separation

The experiment still remaining to be made to complete the series is to size the 20-mesh ore, roast the sized products severally, and then subject them to magnetic treatment.

1. *Crushing.* — The ore used in the work was taken from the main lot, which had been passed through a 20-mesh screen.

2. *Sizing, Roasting, and Magnetic Separation.* — From the screen-analysis given in Table IV it is seen that, in order to obtain 100 grams of ore passing through a 60- and remaining on an 80-mesh sieve, 2,000 grams have to be taken for a test. The unit of ore subjected to roasting was 100 grams, the temperature again 600° C., and the time five minutes. The roasted ore was first treated with the single-pole and then with the double-pole magnet. The results are given in Table IX.

TABLE IX. — Experiments with 20-mesh Material, Sized, Roasted, and Separated

Roasting.							Magnetic Separation.																								
								Heads.																		Tailings.						
								Single-pole.						Double-pole.						Total.												
Size of screen.	Raw ore.	Depth of charge.	Roasted ore.	Loss in roast.	Temperature of muffle.	Duration of roast.	Weight taken.		On weight taken.	On raw ore.	Zinc.	Weight, zinc.	On zinc in the raw ore.		On weight taken.	On raw ore.	Zinc.	Weight, zinc.	On zinc in the raw ore.		On weight taken.	On raw ore.	Weight, zinc.	On zinc in the raw ore.		On weight taken.	On raw ore.	Zinc.	Weight, zinc.	On zinc in the raw ore.	Iron.	Weight, zinc in raw ore, *i.e.*, in heads and tails.
	Gr.	In.	Gr.	%	°C.	Min.	Gr.	Gr.	%	%	%	Gr.	%	Gr.	%	%	%	Gr.	%	Gr.	%	%	Gr.	%	Gr.	%	%	%	Gr.	%	%	%	Gr.
On 40 . . .	100	½	92.6	7.4	600	5	92.6	28.6	30.8	28.6	1.85	0.53	1.52	8.7	9.4	8.7	28.28	2.46	7.05	37.3	40.2	37.3	2.99	8.57	55.3	59.8	55.3	57.73	31.93	91.43	2.28	34.92
On 60 . . .	100	½	93.8	6.2	600	5	93.8	21.7	23.1	21.7	2.59	0.56	1.54	11.4	12.1	11.4	20.85	2.38	6.51	33.1	35.2	33.1	2.94	8.05	60.7	64.8	60.7	55.35	33.57	91.95	3.30	36.51
On 80 . . .	100	½	93.9	6.1	600	5	93.9	20.6	21.9	20.6	2.75	0.56	1.49	10.8	11.5	10.8	18.80	2.03	5.34	31.4	33.4	31.4	2.59	6.83	62.5	66.6	62.5	56.67	35.42	93.17	2.65	38.01
Through 80	100	½	91.3	8.7	600	5	91.3	33.1	36.2	33.1	12.07	3.99	14.22	18.4	20.1	18.4	29.36	5.40	19.24	51.5	56.8	51.5	9.39	33.46	39.8	43.7	39.8	46.95	18.68	66.54	8.12	28.07

In general character they are similar to those recorded in Table VIII, in which the roasting preceded the sizing, but denote an improvement. In the sized material coarser than an 80-mesh screen, about 92 per cent. of the total quantity of zinc is saved in the tailings, which, however, run high in iron, from 2.65 to 3.30 per cent. The ore passing through an 80-mesh screen saves only 66.5 per cent. of the total quantity of zinc, and the tailings assay 8.12 per cent. of iron, which makes the method impracticable.

VIII. Conclusion

The conclusion to be drawn from the experiments points in one direction only. Blende and marcasite in the concentrate under consideration can be successfully separated by crushing through a 20-mesh screen, roasting from five to ten minutes at a temperature not exceeding 600° C., and then subjecting to two double-pole magnets, the first having less than half the strength of the second.

SANITARY PLUMBING AND OUR PLUMBING LAWS

By J. PICKERING PUTNAM, Architect

Addenda to Paper Published in December Number

Figures 9 and 10 of page 323, Volume XVII, taken in connection with the text describing them, give at first sight the impression that the ordinary "pot," or reservoir, traps cannot be used under sinks or in positions where greasy matters abound in the waste water without danger of clogging in such a manner as to convert them in time into S-traps.

This is not the case, and it is very important that the subject should be made perfectly clear, because otherwise it might be supposed that complete safety cannot be obtained with ordinary simple appliances.

It is only necessary to use with all traps proper *flushing appliances* in order to secure entire safety; and where the traps are used under sinks, *special flushing devices*, such as have been invented by Waring, Gerhard, and others, have proved perfectly efficient.

These sink-flushing devices act on the principle of the siphon flush tank, in that they discharge periodically and automatically through the trap and waste pipes a large volume of water after the greasy matters therein have partially cooled and congealed, and thus they prevent the deposit of sediment along the inner walls of the trap and waste pipe.

This point was more clearly brought out in the lecture than in the printed report of it.

The cuts, Figures 9 and 10, were explained in the lecture as follows: —

FIG. 9

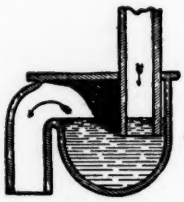

FIG. 10

RESERVOIR TRAPS SHOWING CLOGGING UNDER SINKS DUE TO THE USE OF INSUFFICIENT FLUSHING

The clogging could have been avoided by the use of sinks constructed on the principle of the flush tank as devised and recommended by Waring, Gerhard, and others

Where the vent pipe is used it is evident that it provides a pocket entirely beyond the scouring area of the water flush, and may thus in time become closed by the spattering and condensation of vapor even under powerful flushing, while on the other hand the body of the trap enjoys the full advantage of the scour.

There are many other forms of anti-siphon traps on the market today which are also more or less self-scouring and which were shown in the lecture. With these a simpler flushing device is sufficient to keep them entirely safe from clogging even under sinks. The patents on many of the best of these traps and of the flush sinks have expired, so that the public now has the advantage of the free use without back-venting of pot traps and special flushing sinks, on the one hand, or of self-cleansing anti-siphon traps and simpler flushing devices, on the other, at a minimum cost and with absolute safety.

It should also be added that the unvented pot and other anti-siphon traps can easily be inspected through their clean-out caps, and periodically cleansed in cases where the owner prefers this to the use of the more expensive special flushing sinks. The mouth of the back-vent pipe, on the other hand, is usually altogether inaccessible for cleansing, especially when it is connected with the waste pipe at some distance beyond the crown of the trap. Hence a vented S-trap places the house occupant between Scylla and Charybdis. If the vent mouth is placed near the crown of the trap, it destroys the water seal by evaporation. If it is placed at a distance from the crown, it becomes inaccessible for cleansing. The only safety lies in prohibiting altogether the use of the

"back vent," and in requiring the use of some form of trap which cannot be siphoned, and of fixtures constructed either on the principle of the flush tank or with outlets large enough to provide a thorough water scour. It should be noted that through an error of draughtsmanship in Figure 14 the ice chest and its trap shown on the upper story are placed a few inches too low. Where the refrigerators can be conveniently placed over each other in the different stories of a house, it would be well, where rigid economy is not a prime essential, to connect their traps with a special waste pipe descending to the basement and discharging over a sink, as shown in Figure 15. But the sink trap should be an anti-siphon trap like the rest, without back vent.

The item of back-venting forms a large percentage of the total cost of plumbing today, and where it is a question of alterations of buildings already completed it may easily constitute the principal item of expense. Indeed, the cost item is more often entirely prohibitory in alterations. The house owner prefers, in most cases, to forego the advantages of installing a plumbing fixture in a finished house, even though it may be greatly needed for health and comfort, rather than allow several stories to be cut into and perhaps permanently disfigured for back-venting alone as the price of attaining it.

No part of the building laws of today calls more urgently for immediate amendment than the plumbing laws, and those who are responsible for the present conditions or who permit of their continuance should be required to show some reason for their position.

If objection to immediate change is made on the ground of insufficient information as to the facts, then the whole matter should be placed at once in the hands of an impartial expert commission for investigation. The apparatus necessary for thorough investigation is already available without expense to such a commission, or could be duplicated by them for a sum not exceeding a hundred dollars. With such an apparatus, taken in connection with the published statements and demonstrations of acknowledged authorities in science and bacteriology now accepted by all students of the subject, it remains to be shown why the following points have not been thoroughly proved, namely: —

(1) That the back-venting of traps now required by law is both dangerous and very costly, and that simpler means are now known which afford entire safety with less expense. (The Boston Society of Architects have already voted unanimously for the amendment of this law.)

(2) That the use of the main house trap, equally prescribed, is an evil, having no compensating advantage.

(3) That the method of jointing iron pipes now required is unscientific and unsatisfactory, and that other and entirely suitable methods are now known.

(4) That no proper provision for flushing the waste-pipe system is provided in the statutes.

(5) That the number of traps required is excessive and the provisions for their arrangement unwise.

And finally (6), that the requirements for flushing water-closets are antiquated and unnecessarily costly.

BOOK REVIEWS

Elements of Mechanism[1]

This work was begun twenty years ago, and since that time has been privately printed for the use of students at the Massachusetts Institute of Technology, and is now offered in a thoroughly matured form for general use. Like any work of this nature, which at once exhibits the development and present status of an art or branch of science, the larger part of the matter is standard or even classical, the merit being mainly in the systematic, clear, and practical exposition. But the most recent developments are presented, and originality is shown in methods, applications, and suggestions.

To one whose systematic study of the subject dates back to an earlier time than the beginning of this book, the most salient feature is the fact that the adaptability of forms of mechanism changes as the resources and methods of machine shops improve. The writer remembers being told that involute gears were interesting but not useful, and that chain gearing was rude and wasteful; which was true enough then, but not now.

The work opens with definitions of a machine and of the parts of machines — a necessary but difficult matter, since definitions are expected to be brief and some of the ideas are complex and hard to grasp; it would be interesting to have students required to criticise the fundamental definitions *after* they had completed the subject. Next follows a brief statement of composition of velocities as demanded for this work and the treatment of velocities by aid of the instantaneous axis and the centroid. Having these preliminaries out of the way, the book takes up the real work of this branch of science with a discussion of sliding, turning, and twisting motion — the latter developing the screw and the worm and wheel. From the complete contact of such pairs of elements the authors pass to the infinitesimal contact of rolling cylinders and cams, as illustrated by friction gearing and rolling (*i. e.*, frictionless)

[1] Elements of Mechanism. Peter Schwamb and Allyne L. Merrill. New York: John Wiley & Sons, pp. vi + 264.

cams. Toothed wheels are reserved for separate treatment in a chapter on gearing *par excellence*, that is, toothed gearing. Following this chapter is one on band gearing, which is again with or without friction, depending on whether the bands are belts or cords or are high-speed silent chains which give nearly perfect efficiency of transmission. In this chapter appears a feature that is at least questionable in an elementary text-book, and which continually recurs, namely, an extreme brevity of illustration or description. It may be said, of course, that if some of the *devices* are automatic, this book is not intended to be self-teaching, and something is to be left to the instructor. A simple example of this will be found in the illustration of the chain stripper of Figure 78, page 56, and an extreme case will be found at the end of the chapter on cams, page 72. Here there is outlined, in somewhat more than nine lines, three complicated cam combinations, involving linear, plane, conical, and spherical paths and motions. The student who is to take this flight of scientific imagination will need to be steadied by the systematic and lucid explanations that lead up to it. Otherwise this chapter is simple, direct, and practical, and will enable a student to understand and construct any ordinary cam motion.

The chapter on link work brings into prominence a feature of this book that differentiates it from the conventional text-book on mechanism, which appears to be chiefly a storehouse of mechanical contrivances; this feature is the general educational training that comes from a broad and comprehensive treatment of applied geometry together with the reduction of the general principles to a systematic practical method of application. The chapter runs into the discussion of the crank and connecting rod for the steam engine, and also the eccentrics and eccentric rod for the valve gear. It may be proper to say that valve gears form a continuation of this course in mechanism, and are found to be taught best as an integral part of the course. The chapter is particularly happy in its discussion of the crank and connecting rod, or the slider-crank train with its modifications and inversions, and also in its treatment of the enlargements of elements, as of the crank pin into the eccentric. The chapter on right line or parallel motions, both exact and approximate, has much the same features; in fact, it is a continuation along a special line.

The chapter on intermittent link work takes up all possible forms of ratchet, escapement, and positive stop motions; for example, the watch escapement and the counting and stop gear that prevents overwinding.

Having disposed of the elementary gears, the authors proceed to chapters on trains of wheels and aggregate combinations, in which complicated effects and motions are obtained by building up from the elementary gears, beginning with trains of gears for lathes and clocks and leading through epicyclic bevel trains to the automatic action of the cotton mule.

The discussion of teeth of gear wheels, as already pointed out, is reserved for a special chapter, it being considered that what may be lost by dislocation is more than gained by concentration, especially for a subject that requires such clearness of thinking and nice discrimination; there is also an advantage in reserving this matter till the student has had the advantage of the training of all the preceding chapters. Twisted and hyperbolic gears, which are the delight of the geometrician, have a properly abbreviated treatment, but such practical matters as the line of action, amount of sliding, and conditions to avoid interference are discussed exhaustively.

It is the habit to accompany the instruction with many problems for solution in the class room and drawing room in order to impress the principles and give facility in applying them; and it is to be hoped that such problems may be added to a future edition that is sure to be demanded.

C. H. Peabody.

American Meter Practice[1]

The success of any business enterprise depends on the development and practice of a proper system of charges, and that of electrical supply is no exception to this rule. It may be said that the development of metering devices has had an enormous effect in extending electrical service, for they not only assure the supply company that the customer pays for what he receives, but with the prospective customer it is a potent argument that his bills will be in proportion to the power he uses. If a supply company is to succeed, good meters are an essential portion of its system of distribution. Every one knows this, or should know it, yet cases have come before us where, on account of lack of attention to this matter, the revenues from certain customers have been reduced by as much as 30 per cent. The matter of overcharges

[1] American Meter Practice. By Lyman C. Reed. New York: McGraw, 1903. $2 00.

through defective metering devices is a phase of great importance, for no careful manager will lay himself open to charges of extortion and a consequent loss of customers. Of course, large companies have a just appreciation of these things and keep abreast of progress both in the matter of meters and inspection. Considering the importance of the subject it is surprising that so few attempts have been made to collect information on these matters in such a form that it would appeal to those to whom it is of perhaps the greatest relative concern, that is, to those connected with the smaller plants, where in consequence of false notions of economy old meters may have been retained, and where inspection and testing have been neglected.

The book before us is an attempt to supply this deficiency. The first chapters deal with power measurements in general. This matter is of such fundamental importance that it is worthy of treatment in detail, especially when polyphase systems are considered. These chapters bear evidence of having been put together with less care than they deserve. They would be improved by a discussion of the conventions as to signs in such systems, and by the solution of illustrative examples on E. M. F. and current relations by the vector method, for it is only by this means that errors may be avoided. The following chapter, on "Meter Selection and Torque and Friction," together with Chapter 14, on "Value of Losses in Meters Related to Income," should convince any over-economical manager that he may be practicing false economy in retaining antiquated devices on his system. Chapters 5 to 11 are devoted to descriptions of typical meters; no demonstrations are included. The remainder of the book is devoted to chapters on management of the meter department, including testing, on reading meters, and on differential rating. A brief chapter on photometry is appended, probably with a view to enlightening managers of small stations.

F. A. L.

Geology Applied to Mining[1]

The appearance of a new work on economic geology in this country is always the subject of intense interest and vigorous criticism by geologists and mining men, the former watching jealously the effect on the science, the latter seeking, too often in vain, for a helpful guide

[1] Geology Applied to Mining. By Josiah Edward Spurr. New York: The Engineering and Mining Journal, 1904.

through the mazes of obscure terminology which they have sought in vain to comprehend from Dana, Geikie, or Le Conte. It is always easy to criticise adversely such a book, but very difficult to find the time to write one for one's self; realizing this, the present reviewer welcomes in most friendly spirit Mr. Spurr's efforts, and congratulates him on publication of his book, while reserving the privilege of criticising freely with a view to suggesting improvement for future editions.

The author's motive was to furnish "mining men and students" with a book "stating concisely those results of the science of geology which bear upon ore deposits." On a page later than the preface he limits the subject further by stating that economic geology in general, and this book in particular, deals principally with "the less common of the heavy metals." This is somewhat confusing, for it is commonly believed that coal, iron, copper, oil, the earths, and the natural salts come under the head of economic geology; and it appears in the index that Mr. Spurr gives considerable attention to iron and copper. The order of presentation begins with the processes of ore deposition, then stratified and igneous rocks are treated in turn, then the principles of dynamic and structural geology are considered together, and lastly chemical geology and physiography. The apparent motive for this unusual order was the necessity felt by the author of defining ore deposits first as the subject best known to his readers. He then leads them by questions and answers — the Socratic method, with questions in italics, is used throughout — to the rock in which their ores may occur, treating sediments first. In the chapter on dynamic and structural geology, maps and cross sections, folds, faults and joints, and placers are treated successively. The fifth chapter, dealing with chemical geology, takes up the work of underground waters, surface waters, solution, precipitation, alteration, oxidation, enrichment, ascension, descension, and lateral secretion. The last chapter dismisses briefly the relation of topographic forms to ore deposits.

The material in the book should be of value to men actually engaged in mining who are sufficiently trained in the rudiments of science to understand such expressions as stable crust, sedimentary rocks, recrystallize, conglomerate, micaceous, chloritic, metamorphosis, slipping planes, basic constituents, and magmatic segregation — all of which occur without definition in the first chapter; and the book contains no glossary. It contains a fairly complete summary of theories of ore

deposition as they have been discussed in the *Engineering and Mining Journal* and elsewhere during the last ten years, and is suited to readers of education such as would be required to follow such a journal. For mine foremen and prospectors in the Rocky Mountains, however, the book is as unintelligible as are most of the geological text-books. The first chapter might well discourage even the student of a technical school, dealing as it does with the most obscure phenomena of geology — metamorphism, metasomatism, and concentration.

The reviewer would amend this destructive criticism by making a constructive suggestion — that the author rearrange the order in a future edition and append a glossary of terms. The natural order for leading the lay mind to an understanding of geology — as proved by a half century of the teaching of Agassiz, Shaler, and Le Conte — is to present visible earth processes first, such as movements of water, sediments, earthquakes, volcanoes, and so lead up to the complex structures which are the results of these processes. Mr. Spurr's definitions of "dynamic and structural geology" are incomplete, as he applies them chiefly to phenomena of deformation; and in any case, dynamical geology, dealing with perceptible earth movements of all sorts, should be treated separately from structures. A third improvement recommended, almost essential if such a book is to be really intelligible to non-technical readers, is the insertion of the best possible photographic reproductions of rock surfaces by one of the color or monochrome processes now possible at very moderate cost. Mining men who have not had laboratory training cannot learn to name rocks correctly unless they are shown good pictures of the rocks themselves. Most geological books are doubly confusing in this respect, for not only do they neglect illustration of the actual rock surfaces, but they present microphotographs made by transmitted light which have not the slightest resemblance to the rock itself. The diagrams in "Geology Applied to Mining" are generally good, but many of them would be greatly improved by the introduction of a graduated line to show scale.

In the chapter on structural geology the expression "having a plane direction" (page 121) is not clear. On page 141, where a table is introduced to show the relation of dip to migration of outcrop, trigonometry seems unnecessary; on the other hand, the trigonometric relations of thickness to dip and depth are nowhere explained in the book, and the word "thickness" does not appear either in the index or the text, either for veins or strata. This omission is startling in view of

the fact that the first task of the geologist is to determine thicknesses wherever practicable. Elaborate methods of determining faults are given, some twenty pages being devoted to this subject. Mr. Spurr has written some original papers on faults, which perhaps explains the use of unusual terms, such as "perpendicular separation" as one of the "functions" of a fault movement. It is hard to follow the author, however, when he states and shows by diagram that "the throw may be defined as the distance between two parts of any" (faulted) "body . . . *measured along the fault plane*." The text-books and most geologists define *throw* as the vertical height of one end of a stratum above that from which it has been disconnected; the distance along the fault plane is commonly called "displacement." Such inaccuracies as these are mere details, however, due to a conversational style, which on the whole is very readable and simple. It leads the author to looseness of expression occasionally, but this can be corrected after one or two revisions of the text.

As against these defects, the chapters on igneous rocks, placer deposits, and chemical geology are useful writings, especially the latter. This chapter discusses concisely the movements of underground waters, concentration, replacement, etc., and gives many excellent examples of each phenomenon discussed, with abundant references to modern authors. It is by far the most carefully written essay in the book, and the author writes authoritatively, as his own experience has been large in the mining districts of Alaska, the Rocky Mountains, and Turkey.

Uniformity in Technical Analysis[1]

This pamphlet is a preliminary report of the committee appointed by the American Chemical Society to study the possibility of obtaining more uniform results in technical analytical work. It gives a review of the recent work done in this line, including results of many chemists on standard samples of cement mixtures sent out by a committee consisting of Messrs. Richardson, S. B. Newberry, and H. A. Schaffer, and representing the New York section of the Society of Chemical Industry; results on copper slags sent out by Mr. Thorn Smith; and

[1] Contribution from the Committee on Uniformity in Technical Analysis, I. W. F. Hillebrand, chairman, Charles B. Dudley, H. N. Stokes, and Clifford Richardson, Secretary. Reprint from the Journal of the American Chemical Society, December, 1904.

results on zinc ores sent out by Mr. W. George Waring, of Webb City, Missouri. The samples were sent to various chemists with requests that results be reported, but there was no specification as to method of analysis. The variation in results was extremely large and indicated strongly that the present status of analytical chemistry is in a serious condition. The committee will endeavor to locate the causes of this condition.

In the opinion of the reviewer it seems almost hopeless and useless to expect any uniformity in results when there is such a great variety of methods in use. It would seem very much more logical for the committee to issue, in future, provisional standard methods, and then to invite criticism and discussion in regard to that method with the idea of improving it. Of course, there would be many differences of opinion, but would this not in the end lead to the most important results?

Another point which the reviewer would insist upon is the fineness of the sample. In his experience he has found that there may be considerable segregation even in material which has passed a 100-mesh sieve. In one of the series of samples which have been distributed in the past, this phenomena could readily be seen when this material was shaken in a bottle. This could not account for the extreme variations reported, but may partially account for some of the discrepancies.

In view of the extreme importance of the work of this committee, it is to be hoped that it will receive the support of all chemists and employers of chemists. The policy which they announce is quoted in full: —

1. To use every endeavor to impress upon chemists the necessity for such changes, either in methods of analysis or of manipulation, together with a control of the purity of reagents in use, as will make it possible to arrive at greater uniformity in the results of analyses made by different analysts.

2. To determine whether the lack of uniformity is to be attributed to lack of proper instruction in our schools or to mere carelessness in manipulation, by inviting the coöperation of the instructors in analytical chemistry in the work, distributing among them standard material for analysis, the results of the analysis of which shall demonstrate the accuracy of the method taught by them.

3. To test, in conjunction with the National Bureau of Standards, various methods, and determine their accuracy and suitability for general use.

4. To prepare samples of materials of different character whose exact composition shall have been determined by the most careful analyses of experts.

5. To place such samples in the care of the National Bureau of Standards for preservation and distribution to persons desiring to test their methods of analysis or of manipulation, or to check the work of students or technical chemists employed in works.

6. To invite the coöperation of persons interested in the analysis of any particular class of material, by the organization of sub-committees for the preparation and distribu-

tion of samples, the chairman of which shall be, for the time being, a member of the general committee and entitled to vote on the subject which his sub-committee has under consideration.

It will not be the policy of this committee to commit the society as a body to the endorsement of any methods as standard, but merely to recommend such as may be found satisfactory. Nor will the committee intrude on fields of work that may be already well covered by existing organizations, such as the Society of Official Agricultural Chemists.

Chemistry of Cyanide Solutions[1]

The author says in his preface that his "object has been not so much to give the results of any special researches on individual obscure points as to present a comprehensive and, as far as possible, complete review of the entire subject. For this purpose a short description of well-known methods is introduced, and when necessary a critical discussion of their value. I have also described the various modifications of existing methods that have been suggested from time to time, but which have not hitherto been collected and compared, and have given results of experiments made to test the accuracy of the assumptions on which such modifications are based."

This abstract from the preface well defines the scope of the book. As an attempt to collect the literature of the analytical methods which have a bearing on cyanide solutions with the many substances which under the conditions of working may be found in them, the book is a success and of considerable value. Whether or not this kind of a book is wanted is another question. The reviewer feels that the worker in this field would have been much better satisfied if fewer methods had been given, and the results of the author's experimental work had been summarized and not left in the form of tables for the worker to interpret himself. Furthermore, as to choice of methods the chemist would be bewildered by the many modifications. It is to be hoped that the author will some day modify the book so as to give some standard methods which he can recommend as the result of his experience in this field.

H. F.

[1] The Chemistry of Cyanide Solutions Resulting from the Treatment of Ores. By J. E. Clennell, B.Sc. New York and London: The Engineering and Mining Journal, 1904, iv + 160 pp. Price, $2.50.